Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

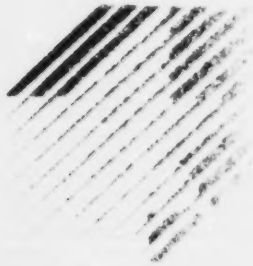
CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

MINERAL SCIENCES LABORATORIES ANNUAL REPORT 1986/87

APRIL 1987

CANADA AWARDS FOR EXCELLENCE 1986

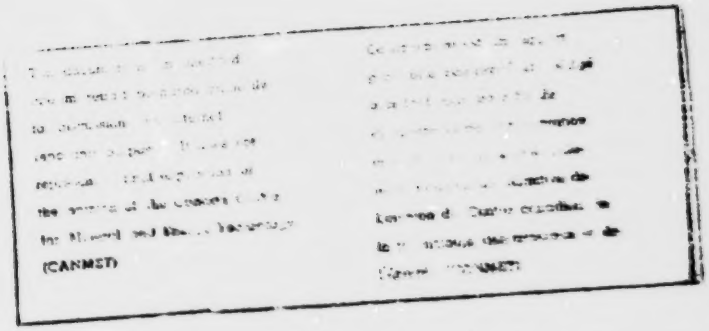


SILVER AWARD IN TECHNOLOGY TRANSFER

Canada

MINERAL SCIENCES LABORATORIES

ANNUAL REPORT 1986/87



MICROMEDIA

CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY

ENERGY, MINES AND RESOURCES CANADA

DIVISION REPORT MSL 87-85 (TR)

169 pp

FOREWORD

The Annual Report of the Mineral Sciences Laboratories for 1986/87 contains an overview of the accomplishments and activities of the division during this fiscal year. The preparation of an annual report enlists the good will and effort of the entire staff; special acknowledgement should go to Mrs. Mabel Palmer and Mr. Lloyd Dalton who coordinated this year's report.

The cover incorporates the logo of the Canada Awards for Excellence, 1986. This silver award in technology transfer was presented to Almax Industries (1980) Ltd., The Canada Centre for Mineral and Energy Technology (CANMET) and Queen's University for the successful development and well-managed transfer of technology used to manufacture efficiently high performance ceramics. This award is sponsored by the Department of Regional Industrial Expansion and was received for CANMET by Dr. T.A. Wheat of the Mineral Sciences Laboratories.

New features have been incorporated this year to provide a more detailed and comprehensive overview of the activities of the laboratories and include: ongoing Mineral Development Agreement studies; significant contacts with industry, universities and government.

Comments from readers are very welcome and should be directed to:

L.L. Sirois
Director
Mineral Sciences Laboratories

AVANT-PROPOS

Le présent rapport annuel des Laboratoires des sciences minérales donne un aperçu des réalisations et des activités de la Division au cours de l'année financière 1986-1987. La préparation du rapport annuel fait appel à la bonne volonté et à la participation de tout le personnel de la Division; nous désirons remercier tout spécialement Mme. Mabel Palmer et M. Lloyd Dalton qui ont coordonné la compilation du rapport.

La nouvelle couverture du rapport illustre le logo du prix d'Excellence du Canada pour 1986. Cette palme d'argent, honorant le transfert de technologie a été remise à Almax Industries (1980) ltd., au Centre canadien de la technologie des minéraux et de l'énergie et à l'Université Queen's pour leurs travaux de développement et de bonne gestion pour le transfert de la technologie utilisée dans la fabrication de céramiques à haute performance. Ce prix d'excellence, parrainé par le ministére de l'Expansion industrielle régionale, a été remis au Dr. T.A. Wheat des Laboratoires des sciences minérales, qui a reçu le prix au nom du CANMET.

Cette année, nous présentons de nouveaux articles dans le rapport annuel, afin de donner un aperçu plus détaillé des activités au sein des laboratoires. Ces articles traiteront, entre autres, des études en cours dans le cadre des Ententes sur l'exploitation minérale; et des contacts importants avec l'industrie, les universités et le gouvernement.

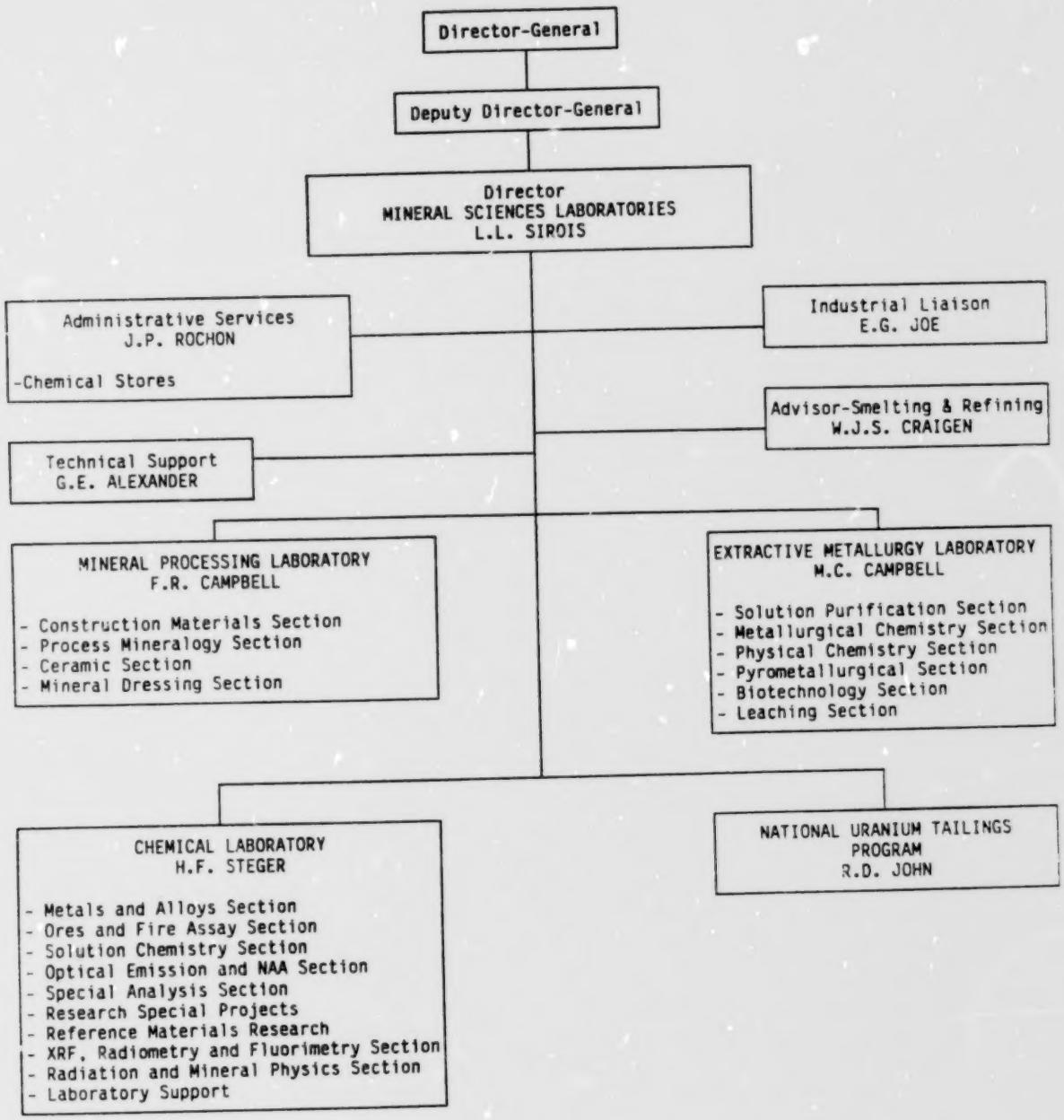
Nous invitons les lecteurs à nous faire parvenir leurs commentaires en les adressant à:

L.L. Sirois
Directeur
Laboratoires des sciences minérales

ORGANIZATION AND PROFESSIONAL STAFF

CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY (CANMET)

MINERAL SCIENCES LABORATORIES



DISTRIBUTION OF RESOURCES

MSL - FISCAL YEAR 1986-87

PROGRAM - MINERAL AND EARTH SCIENCES
ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
14. MINING	
- Personnel (PY)	132(3)
- Operating	19
- Capital	20
20. COAL MINING AND PREPARATION	
- Personnel (PY)	220(5)
- Operating	75
- Capital	18
30. MINERAL PROCESSING	
- Personnel (PY)	7,392(169)
- Operating	1,047
- Capital	322
50. FUELS TECHNOLOGY	
- Personnel (PY)	44(1)
- Operating	20
- Capital	20
70. METALS AND MATERIALS	
- Personnel (PY)	132(3)
- Operating	10
- Capital	10
ACTIVITY TOTAL	
- Personnel (PY)	7,920(181)
- Operating	1,171
- Capital	390

PROGRAM - MINERAL AND EARTH SCIENCES
ACTIVITY - ENERGY R&D

SUB-ACTIVITY	MSL $000's
14. MINING	
- Personnel (PY)	Nil
- Operating	Nil
- Capital	Nil
20. COAL MINING AND PREPARATION	
- Personnel (PY)	Nil
- Operating	Nil
- Capital	220
30. MINERAL PROCESSING	
- Personnel (PY)	250(5)
- Operating	285
- Capital	251
50. FUELS TECHNOLOGY	
- Personnel (PY)	50(1)
- Operating	20
- Capital	30
70. METALS AND MATERIALS	
- Personnel (PY)	
- Operating	
- Capital	
ACTIVITY TOTAL	
- Personnel (PY)	300(6)
- Operating	305
- Capital	501

PROGRAM - MINERAL DEVELOPMENT AGREEMENT
ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	128(4)
- Operating	55
- Capital	Nil

PROGRAM - BIOTECHNOLOGY
ACTIVITY - "A BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	Nil
- Operating	25
- Capital	Nil

PROGRAM - ASBESTOS TECHNOLOGY
ACTIVITY - "A BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	Nil
- Operating	53
- Capital	25

NATIONAL URANIUM TAILINGS PROGRAM
ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	132(3)
- Operating	1,194
- Capital	Nil

HIGHLIGHTS

CHEMICAL LABORATORY

The Chemical Laboratory carries out analytical support services for, and research in the development of analytical methodology for CANMET's Mineral and Earth Sciences Program; provides a consulting service and technical assistance in the field of analytical chemistry to other federal and provincial government departments and agencies, and to industrial organizations and universities; prepares, certifies and distributes Reference Materials to improve quality control in the Canadian Minerals processing industry; participates in committee work for national and international organizations; and provides the sole Canadian analytical umpire service for uranium determination in uranium concentrates to resolve disputes between supplier and refiner.

During this review period, research in and development of analytical methodology using liquid and gas chromatography was continued. Dynamic ion-exchange liquid chromatography was applied directly for determining rare earth elements and yttrium in steels, non-ferrous alloys, advanced materials and uranium ore processing products. Contributions to liquid chromatographic methodology were made for determining low molecular weight organic acids in leachates from studies on biological oxygen barriers for mine tailings deposits; chloride, cyanide and sulphoxy anions in cyanide barren effluents from water pollution control investigations; and sulphite and sulphate for application to a broad range of sample type. Capillary gas chromatography was applied in estimating the extent of oxidation and decomposition of isodecanol and diethyleneglycol dibutylether phases in solvent extraction studies of gold.

Atomic-absorption spectrometry (AAS), inductively-coupled plasma-atomic emission spectrometry (ICPAES) and X-ray fluorescence spectrometry (XRF) were applied for the rapid and direct determination of many elements in solution samples from hydrometallurgical process, ferrous and non-ferrous alloys, environmental materials. During this review period, a second ICPAES instrument was put into routine, analytical service. A microwave preparation system was procured to expedite sample dissolution for the determination of arsenic and antimony by ICPAES. A method using XRF was developed for the direct determination of elements of atomic number > 21 in organic solutions. A graphite furnace AAS procedure to determine trace to minor levels of arsenic in ores and related materials was developed.

The analytical manual "Assay Methods Used in CANMET for the Determination of Precious Metals" SP86-1E was issued and became the most requested CANMET publication late in this review period.

The Chemical Laboratory through the Canadian Certified Reference Materials Project (CCRMP) provided the Canadian industry with compositional certified reference materials that are characteristic of Canadian mining and mineralogical sites. Revenue from the sale of CCRMP products increased approximately 10% last year to $120,000. Three gold ores, two vegetative materials for radionuclides and a uranium ore were certified and offered for sale; interlaboratory programs for a uranium concentrate (yellowcake) and a copper concentrate have been completed; and certification of a suite of seven zinc-aluminum alloys and of a rare earth britholite reference material is nearing completion. CCRMP facilities continued to serve as a resource centre for reference material preparation for four projects by industry and other agencies.

Participation continued in national and international committee work, in particular for the International Organization for Standardization (ISO). Some examples were REMCO, the Council Committee on Reference Materials; TC 102 for iron ore standards; and TC 183 for standard methods of chemical analysis of copper, lead and zinc ores and concentrates. Chemical Laboratory staff also participated in the preparation of a manual for the International Atomic Energy Agency on the analytical chemistry for the uranium exploration, mining and milling industry.

The Chemical Laboratory participated in MSL cost recovery work. Analytical support was provided for projects such as the Royal Canadian Mint Sweeps and Waite Amulet Tailings being carried out by the Extractive Metallurgy and Mineral Processing Laboratories. Reference materials were prepared by the CCRMP for the Aluminum Company of Canada, the International Atomic Energy Agency and Environment Canada. Methods were developed for the determination of geological track dating. Cost recovery projects for dating samples were carried out for the University of Ottawa and the Saskatchewan Research Council.

A computerized sample-tracking system was installed in the Chemical Laboratory. It is based on IBM compatible microcomputers, a Novell local area network (LAN) and multi-access Dataflex software. There will be more efficient and effective sample management and, of importance to Chemical Laboratory clients, more frequent and up-to-date sample reporting capability.

A cooperative project with the Physical Metallurgy Research Laboratories on amorphous alloys was initiated. Apparatus to study magnetic and thermodynamic effects of FeZr and FeNdB alloys is being set-up.

EXTRACTIVE METALLURGY LABORATORY

The Extractive Metallurgy Laboratory contributes to the science and technology of the mineral system with a range of activities from improving the knowledge base to resolving in-plant problems of industry. The breadth and scope of research activities is influenced on preceived gaps in information and technology, changing policy directions, advice from industry and direct request for work by corporate clients.

The ultimate objective is to transfer useful and timely technology to the Canadian mineral industry. The effectiveness of such technology transfer can be identified in the following terms:

a) Development of process technology for the recovery and recycle of cyanide from gold mill effluents.

b) Process development for clients in the recovery of nickel, gallium and rare earths.

c) Scientific and technical support of in-place, biologically-assisted, leaching projects in Ontario and Manitoba.

d) Evaluation of further processing alternatives for antimony production.

e) Recovery of precious metals from metallurgical wastes.

f) Biological destruction of hydrocarbons prior to flotation of a copper-molybdenum ore.

g) Development of an arsenic probe for off-gas control.

h) Characterization of metallic phases in copper electro-refining anode slimes.

The mix of research activities includes the examination of more fundamental aspects of scientific phenomena. Work on photoelectrochemical effects of mineral surfaces is indicating potential for photoelectrical enhancement and control of hydrometallurgical reactions. Low cost materials such as hematite may be effective in photocatalytic processes.

Iron control in hydrometallurgical circuits was highlighted in 1986 with a special CIM Hydrometallurgy meeting in Toronto spearheaded by CANMET. In-house research on iron control and the chemistry of other species in solution has advanced the understanding of the dissolution and precipitation of metallic species. This work is leading to improve metal recoveries in the zinc and copper industries.

Electrochemical research has been instrumental in improving the control and efficiency of electrolytic process plants. A major cooperative study of copper refining has advanced the understanding of processes by the Canadian industry. A comprehensive study on aqueous and fused salt lead electrolysis was completed under contract.

The search for processes to improve metal recoveries and reduce the environmental impact in sulphide ore treatment has led to the development of a ferric chloride leach process. Significant improvements have been made in the cementation and solution purification stages of the process. These flowsheet changes have produced a process which may provide an economical attractive route to high recoveries from complex sulphide ore deposits.

Biotechnology has been identified as one of the emerging technologies. There is ample evidence that biological species interact with mineral systems. The network, BIOMINET, has been instrumental in improving communications between the many disciplines related to this field. In-house research has been effective in identifying heterotropic bacteria which selectively leach nickel. Work in collaboration with contractors and industrial clients is showing significant advances in biosorption of metals, bioaccumulation of elements such as selenium, and biodestruction of hydrocarbons and cyanide.

A comprehensive project to evaluate alternative processes for uranium recovery has been completed. Spinoff from this work has led to improvements in the existing uranium technology and in the recovery of other metals such as rare earths, gallium, nickel, gold and platinum group metals. This work has been a vehicle for significant improvements in solvent extraction and ion exchange technologies.

The high level of interest in gold has been reflected in ongoing research. A number of alternative pretreatment and leaching systems have been identified and tested in comparison with cyanide. Recovery of gold from solution using new ion exchange system has yielded encouraging results. The recovery of cyanide from barren solutions has continued to occupy resources in perfecting the acidification-volatilization-reneutralization (AVR) approach, evaluating reverse osmosis and assessing ion exchange techniques. Work on gold has also found a natural extension into separation of platinum group metals.

The increased interest in effective tailings management and abandonment technologies has strengthened the level of cooperation between industry and the research community. Work on more fully elucidating the physical, chemical and biological mechanisms in acid drainage production has continued. The effectiveness of cover materials including deep water is being clearly indicated.

Pyrometallurgical research has shown the potential for improved non-ferrous slag cleaning using a high iron sulphide matte. An improved data base on the arsenic oxide system is enabling the development of an arsenic probe. The evaluation of limestones for desulphurization in fluidized bed combustion of coal has been perfected in a circulating fluidized bed. A wide range of limestones have been tested.

Service to other organizations is part of the challenge of the scientific community. Recognition is received in the form of awards. Dr. R. Sutarno received the John L. Haque Award from the American Society for Testing and Material (ASTM) for his contributions to standards development for sampling and analysis of metal bearing ores. Dr. Sutarno has been a major contributor to the work of the International Standards Organization in the field of statistical analysis.

This overview provides a brief insight into the activities and highlights of the Extractive Metallurgy Laboratory. Details of the work are more fully outlined in the body of this report.

MINERAL PROCESSING LABORATORY

The Mineral Processing Laboratory carries out in-house investigations and contract studies in support of the needs of the Canadian minerals industry. The program is developed in close consultation with industry and with the provinces (through Mineral Development Agreements) and is carried out in cooperation with industrial R&D performers, private research companies, provincial research organizations and universities. Major projects are underway in the processing of metallic ores, coal, and industrial minerals, in the development and testing of improved construction materials, especially concretes, and in the preparation and treatment of ceramic products, both traditional and advanced. These activities are supported by a range of mineralogical investigations, particularly aimed at process design and optimization.

For its work in transferring advanced ceramics technology to Canadian industry, CANMET was awarded the 1986 Silver Medal in the Canada Awards for Excellence. CANMET shares the award with Almax Industries and Queen's University for the successful transfer of know-how and expertise related to the composition, preparation and processing of piezoelectric ceramics for use in sonar transducers and ionically conducting ceramics for use in thermoelectric generators and sodium-sulphur batteries. The development of these products has allowed Almax to grow from a start-up company to a high tech ceramics research and manufacturing company with almost 100 employees. Dr. T.A. Wheat of MPL has been the principal scientist involved in the development and transfer of the technology.

While perhaps the most successful CANMET/industry alliance in the ceramics field, the Almax story is not unique. MPL scientists have developed cooperative programs with a number of other Canadian firms interested in advanced ceramics technology. These programs include CANMET technical and financial support for industry R&D, access to CANMET expertise and attachement of industry staff to work in CANMET's facilities.

In construction materials, as part of our program to increase the use of supplementary cementing materials in concrete, work in MPL has produced a superplasticized concrete with a fly ash content much higher than previously thought practicable. This concrete has had more than half of its cement replaced by fly ash, yet exhibits higher strength and higher modulus than control concrete. Another major advantage is that this concrete has a much lower heat of hydration so that very large sections can be placed without the formation of internal cracks due to thermally induced stresses.

Also within this same field, MPL has launched a major study on a long-standing problem-alkali-aggregate reactivity. Widespread structural deterioration results during the lifetime of structures from the reaction of alkali in cements with certain types of silica present in aggregates. With a combination of in-house and contract work, MPL is collecting information on the extent of the problem, identifying certain regional sources of aggregate which exhibit reactivity, and developing the use of supplementary cementing materials to control the above reactions.

MPL's unique mineralogical expertise and facilities have been in great demand again over the past year and our ability to respond to these demands will continue to improve as new equipment becomes fully operational. Of particular interest and value over the period were i) detailed mineralogical characterization of sulphide tailings, the results of which have made a major contribution to our understanding of the serious environmental problems associated with acid generation in these tailings; ii) mineralogical investigation of the nature of copper anode slimes which has been very well received by industry and which promises to lead to improved impurity control in copper refining; iii) the second Image Analysis Workshop, which attracted 30 participants, half of whom were from operating companies. MPL expertise in image analysis is being transferred to companies either installing or proposing to manufacture such equipment in Canada; iv) the start of detailed mineralogical investigations of gold ores using techniques such as electron microprobe, ion microprobe and micro-PIXE. CANMET has provided technical and financial support for the development and operation of installations of these last two instruments at Canadian universities.

In ore dressing, usage of the SPOC family of programs by Canadian industry has increased dramatically over the past year following conversion of the software to the IBM PC system and increased efforts by MPL staff to "market" it. A highly successful and well received workshop was held at Bathurst, N.B. to train prospective users; more are planned for this coming year at other locations. Sales of the SPOC methodology have now exceeded 120 and are increasing at the rate of 5 per month. The next generation of computer assisted mineral processing methods is now under development - expert systems. MPL scientists are taking the lead in this area and are acting as a catalyst to bring together knowledge engineering experts and users in the minerals industry.

Still in ore dressing, energy conservation programs to investigate at pilot-plant scale the effect of grinding aids, use of high efficiency classifiers, various grinding mill/classifier configurations, etc., have indicated a 50% reduction in unit energy consumption. A project is being designated to evaluate energy savings attainable in a commercial cement grinding circuit by incorporating roller mills, high efficiency classifiers and on-stream particle size analysis and control. Processing of placer gold from the Yukon or from off-shore Atlantic provinces has expanded our knowledge of sampling and processing requirements for recovery of fine size gold, and to meet environmental requirements. Wet processing of asbestos tailings has led to the development of low fines content fibres for plastics and asbestos cement applications, and the high level of interest expressed by potential customers has resulted in plans for a 6 fold increase in the pilot-plant capacity at Cassiar Asbestos. The development of perm roll high intensity magnetic separators has resulted in spectacular improvements in CANMET's efforts to separate ash and pyrite from coal, clay from potash, and silica from iron ore. Laboratory and pilot-plant processing of celestite, talc and chromite ores have yielded improved metallurgical results which are being used to reassess the feasibility of property development.

THE NATIONAL URANIUM TAILINGS PROGRAM

In 1981, after a year-long study, the National Technical Planning Group on uranium tailings research, under the direction of Philip Lapp, concluded that there was not enough scientific data to predict confidently the long-term effects of uranium tailings on the environment. This group of experts, appointed by Energy, Mines and Resources Canada, recommended that a research program be conducted to fill the knowledge gap. The Government of Canada responded to this recommendation by announcing in 1982 the formation of the National Uranium Tailings Program (NUTP). This is a five-year research program with approximately $8.5 million in funds that is studying the ways to predict the effects on human health and environment of uranium mill tailings over the long term.

The main objective of the Program is to provide a scientifically credible information base which will assist government regulatory agencies and mining industry to establish long-term management strategies for the protection of the public and the environment. The Program is reviewed and receives advice from a Technical Advisory Committee (TAC) which includes representatives from both Federal and Provincial governments and members of Canada's active mining industry. This group meets on a regular basis and reviews the work done to date and makes recommendations for future work. In addition to providing theoretical and technical assistance, the mining company representatives have also provided practical help which has allowed several projects to proceed smoothly. The TAC has also been a forum for raising issues of joint concern between the industry and various governments involved. Once these issues were identified, the NUTP were able to initiate projects that developed sufficient data to make rational decisions.

A secondary objective is to develop the scientific skills required to assess long-term effects of uranium mill tailings in Canada. In particular, it is hoped to encourage the development of environmental research expertise with the private sector. To this end, the bulk of the research program has been awarded by competitive bid to privately owned Canadian consulting and research companies.

The fiscal year under review is the final one for the NUTP. Thus, the remaining resources ($1.2M, 3PY) have been spent to consolidate the work of previous years to meet the program's objective.

In the area of mathematical modelling, the work concentrated on finishing model development, then application to two existing tailings sites. In parallel, effort was directed towards gaining further confidence in the model by comparing its results to those of other models, and by subjecting it to a peer review.

In the area of disposal technology, the major effort has been on the production of a manual which addresses the long-term implications of various methods of tailings management disposal.

In the area of fundamental research, further work was done to understand the chemical and physical behaviour of thorium, arsenic and nickel, and the oxidation of pyrite.

During the year, as the program wound down, staff members transferred to other positions, though the necessary expertise to conclude the program remained available. At year end, two out of eight full-time staff remained. Fifteen new contracts were initiated in 1986/87, which along with eight ongoing contracts made a total of twenty-three for the year. As well,

there were seven publications by NUTP staff in conference proceedings, journals and EMR publications.

MINERAL DEVELOPMENT AGREEMENTS

Under the "umbrella" of the Economic and Regional Development Agreements, the federal government and the provinces have established a number of federal/provincial Mineral Development Agreements (MDA's). The objective of these agreements is to strengthen and diversify the mineral industry in a province to enable minerals to make a maximum contribution to the provincial economy and to reduce the impact of economic down-turns. Projects undertaken identify and evaluate mineral deposits and develop appropriate mineral processing and extraction methods in order to promote and accelerate development opportunities.

The Mineral Sciences Laboratories of CANMET has major responsibilities for the Mineral Technology component of those MDA's which involve joint federal/provincial program delivery. (Certain MDA's are solely provincially delivered.) Thus MSL is involved directly in MDA's with Newfoundland, Nova Scotia, New Brunswick, Manitoba and Saskatchewan and plays an advisory role in Agreements with Quebec, British Columbia and the Yukon Territory. The research work is carried out by contractors selected from industry or from private or provincial research organizations. MSL's role is, in consultation with the provinces, to prepare work programs, provide expert advice and guidance and act as Scientific Authorities on contracts. With perhaps 20 MDA contracts underway and 86/87 expenditure nearing $3.5M, this is a major element of MSL's program and places a large demand on MSL staff.

During the 86/87 period, the effort in the Newfoundland MDA was directed towards improved iron ore processing and the assessment of base metal sulphide deposits. In Nova Scotia, work was focussed on identifying and developing new sources of industrial minerals and construction materials while in New Brunswick, focus was on construction materials and developing extractive processes for sulphide minerals. In Manitoba, most work was devoted to the reduction of sulphur emissions in the extraction of sulphide ores, and in Saskatchewan, to the dry processing of potash.

In subsequent sections of this document, MDA contracts are described as part of the Project under which they fall (e.g., the Newfoundland MDA contracts on iron ore are described under the MSL Project Iron Ore Processing). MDA contracts are designated as such by the letters MDA written after the Contract Requisition Number.

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SPECIAL AWARDS

CANMET shared the 1986 Silver Medal with Queen's University and Aimax Industries in the Canada Awards for Excellence for technology transfer. T.A. Wheat was the principal CANMET scientist involved in the transfer of advanced ceramics technology.

A.K. Kuriakose and A.J. Hanson won an award for their entry entitled "Silicon Carbide from Carbon and Silica" at the Annual Ceramagraphic Competition sponsored by the Canadian Ceramic Society in February, 1987.

V.M. Malhotra was elected an Honorary Member of the American Concrete Institute. He is the youngest person ever to be so named. In addition, the Organizing Committee of the International Conference on Fly Ash, Slag, Silica Fume and Natural Pozzolans have named the Supplementary Cementing Award after him.

R. McCready and M.C. Campbell received the Award of Distinction in the Scholarly Article Category from the Society of Technical Communications for an article on biotechnology in GEOS.

R. Sutarno received the John L. Hague award from the Americal Society for Testing and Materials for technical contributions to standards development.

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PART A. RESEARCH AND DEVELOPMENT

MINERAL AND ENERGY TECHNOLOGY ACTIVITY

MINING SUB-ACTIVITY

Rock Mechanics

- Project 14.25.05: Underground Nuclear Waste Repository
  Project leader : V.V. Mirkovich

Objective:

To characterize petrographically rocks occurring in sites being examined for possible disposal of nuclear wastes, and determine their thermophysical properties from representative specimens.

(a) Measurements of thermal conductivity, thermal diffusivity and linear thermal expansion of samples from the Underground Research Laboratory at Pinawa, Manitoba have been completed. Reports on thermophysical properties and petrographic characteristics are in preparation.

(b) A cooperative project between CANMET and Lawrence Livermore National Laboratory, University of California, on measurement of thermal diffusivity at high pressures was successfully completed. Seven types of low porosity rocks, originating from potential underground nuclear waste rock repositories, were studied. For some of the rocks results revealed herertofore unknown thermal transport characteristics.

(c) Rock samples from the East Bull Lake Area, Ontario, were selected for determination of their thermal properties. Specimen preparation for measurement of thermal conductivity, diffusivity and expansion is in progress.

Publication:

- W.B., Durham, V.V., Mirkovich and H.C., Heard, "Thermal diffusivity of igneous rocks under pressure"; Lawrence Livermore Nat. Laboratory, Report UCRL-96761, Livermore, California (1986). (Accepted for published in J. Geophysical Research).

Mine Environment

- Project 14.39.01: Ventilation and Respirable Dust
  Project leader : J. Bigu (MRL)

Objective:

To characterize dust in underground and surface mines, assess sources and control measures, and develop methods of measurement.

(a) Infrared determination of quartz in mine dust

In order to prepare samples of quartz on filter membranes by air deposition in the laboratory, a small dust chamber was constructed. The sampling system consisted of a 25 mm diameter Millipore filter cassette with a DM 800 filter membrane, a 10 mm nylon cyclone and a Gilian HFS pump. The flowrate through the sampling train was 1.7 L/min. The dust cloud was created from ground silica sand or from NBS respirable alpha quartz.

Uneven performance of the sampling system led to an investigation of the effect of the outlet configuration on the deposition pattern of the dust. By separately examining the central portion and the edges of a deposit, variations in thickness and quartz particle size diameter were estimated. It was found that the support pad normally placed behind the filter in the Millipore cassette was not of sufficient thickness to prevent varying deposition patterns and/or the loss of quartz through leakage around the edge of the filter. Deposits having a consistent pattern of a thicker centre sloping symmetrically to the edge resulted when the pad thickness was doubled.

Deposits having a mass range of 98-800 µg quartz were used to prepare a calibration curve. The correlation coefficient for the three-term regression through zero, normally used for quartz calibration, was 0.9995. While some distortion in deposition could result from the fact that the sampling system sampled a more dense dust cloud in the dust chamber than that normally encountered in the field, the indication is that the standardization of only the pump and cyclone will not define performance and that the outlet configuration through the filter must be examined as well.

Quartz deposits have been examined on the newly acquired Digilab FTIR spectrophotometer. Sample holders with 20 mm diameter masks were constructed to accommodate the circular beam. QUANT 32 software has been applied to identify and calculate quartz doublet parameters.

(b) Dust suppression

Suppression of dust generated in hard rock mines has been investigated in the laboratory. Surfactants effective in reducing dust were identified and a method to eliminate their detrimental effect in subsequent recovery processes was developed. This method uses activated carbon to adsorb the wetting agents prior to the recovery process.

The method was first applied to a single mineral flotation (Opemiska copper ore) and then extended to a more difficult case of a multi-mineral ore requiring selective flotation (Kidd Creek ore). It was found that even under an excessive addition of dust-suppressing wetting agent, the carbon

adsorption method can eliminate the detrimental effect of the surfactant and render the ore amenable to flotation.

Underground experiments are required to evaluate the efficiency of dust suppressing surfactants and testwork in MSL's CPDU is needed to verify the carbon adsorption technique for wetting agent removal. The research work in the laboratory will continue to evaluate the adsorption characteristics of the carbon and to study alternate routes for surfactant removal.

Some initiatives were also taken to examine possible application of these wetting agents to control dust in the coal industry.

Reports:

- M.A. Cristovici, "Investigation to control mine dust using surfactants and a new approach for eliminating their negative effect on flotation"; October 1986; Division Report MSL 86-132 (OP).

- M.A. Cristovici, T. Gilmour, "Investigation to eliminate the detrimental effect of dust-suppressing wetting agents on flotation results (Opemiska ore)"; April 1986; Division Report MSL 86-65 (IR).

COAL MINING AND PREPARATION SUB-ACTIVITY

Coal Desulphurization

- Project 20.79.01: High Sulphur Coal
  Project leader : K.S. Moon

Objective:

To contribute to the technology of economically upgrading high sulphur coals to meet more stringent specifications for thermal and metallurgical coals and future requirements for coal combustion, conversion and environmental considerations.

Coal preparation to remove ash, sulphur an other contaminants will generally be necessary for coal destined for liquefaction and gasification. Preparation will also be increasingly important in thermal coal production, especially to reduce sulphur in eastern coals, as atmospheric environmental regulations become more stringent. In the future metallurgical coal will be produced from poorer quality raw coal requiring improved fine and oxidized coal treatment. Removal of unwanted components also contributes to decreased transportation costs.

(a) Magnetic treatment of Canadian coals

The dry magnetic beneficiation of Canadian coals was completed on Prince and Lingan (DEVCO), Kipp (Petro Canada) and Crows-Nest coals using both the high-gradient conventional and superconducting separators. Promising results were obtained in all cases. Currently an open-gradient cryogenic magnetic separator is being tested; about 50% of the research with this unit is now complete. Upon its completion, a comprehensive report will be issued to compare the performance, efficiency and operating costs of the various machines. Considerable delays have occurred in completing the contract with Cryogenic Consultants in Britain.

(b) Deep cleaning of high sulphur coals

A literature survey on the petrography and mineralogy of Eastern coals was made to support and complement our work on their deep-cleaning by progressive grinding, flotation and magnetic separation. It was found that the beneficiation, while a novel approach, behaved as predicted by the mineralogical data on grain size and liberation. The ash and sulphur minerals removed from the Lingan and Prince coals attained about 95%, thus giving coal products with less than 1% ash and sulphur (Lingan) and 2% ash and sulphur (Prince). A report was written on this subject matter for publication by AIME. Ultimate cleaning of the DEVCO Donkin coal was made using the same methodology. The final coal products attained 1% ash and 1.5% sulphur with 85% thermal yield. The results will be presented at the International Coal Preparation Conference in the near future.

(c) Dry processing of coal (New Project)

Several Canadian coals are being preconcentrated at coarse size using novel rare-earth permanent magnetic rolls. About half of the samples tested responded well to the treatment. Work is continuing to determine the main parameters of the separators and to optimize the results. Capacity and cost studies will be made on the conditions yielding the best results.

(d) Column flotation of ultrafine high sulphur coal

A series of column flotation tests was conducted after ultrafine grinding using a Szego Mill. The results are being analysed for the effect of multiple passes through the Szego mill on column flotation. Further studies on various grinding and flotation conditions will be conducted through contract research.

(e) Selective biodepression of pyrite from coal

Selective biodepression of pyrite during coal flotation has been studied with Thiobacillus ferroxidans on high sulphur coals from Eastern Canada. Results indicate that some of coal pyrites respond to the process positively, and others indifferently. As studies in other countries gave similar indications the process will have to be studied more carefully before any commercial application.

(f) Development of "CANMET Sulphur Form Analyser"

A prototype CANMET Sulphur Form Analyser is being developed for the quantitative analysis of different sulphur forms in coals, based on the patent-pending process developed in CANMET.

Contracts:

- Reqn. 4-9164, "Dry magnetic separation of eastern Canadian coal", Cryogenic Consultants Ltd., U.K. S.A. - G. Mathieu.

- Reqn. 4-9189, "Selective biodepression of coal-pyrite from coal in flotation desulphurization of high sulphur coals", B.C. Research. S.A. - K.S. Moon.

- Reqn. 5-9219, "Development of a prototype CANMET SULPHUR-FORM ANALYSER", Barringer Research Limited. S.A. - K.S. Moon.

Reports/Publications:

- J.S. Laskowski, M. Bustin, L.L. Sirois and K.S. Moon, "Desulphuring flotation of eastern Canadian high-sulphur coals"; Processing and Utilization of High Sulfur Coals 247-266; 1986.

- K.S. Moon, "Theory and industrial application of column flotation"; Division Report MSL 86-166 (IR).

- K.S. Moon, "Analysis of pure coal content using proximate and thermal analyses for the evaluation of pure coal recovery in a coal cleaning process", Division Report MSL 86-165 (IR).

MINERAL PROCESSING SUB-ACTIVITY

Minerals Evaluation

- Project 30.05.01: Mineralogical Evaluation of Ores
  Project leader : P.R. Mainwaring

Objective:

To promote the development of Canadian mineral resources including various large tonnage, low grade and complex deposits of metallic minerals as well as known industrial mineral occurrences by detailed study and assessment of the mineralogy, valuable element distribution, and probable liberation characteristics and by subsequent laboratory bench tests directed toward the improved recovery of the contained minerals.

(a) A study of the occurrence and recovery of gold in the copper and cobalt-bearing mineralization of the Windy Craggy deposit, N.W. British Columbia has been completed. Most of the gold in the feed is recoverable by a flotation-cyanidation scheme where a copper concentrate is also recovered by flotation. Potential recovery better than 87% was indicated.

(b) Mineralogical characterization of the difficult-to-process ores of the Anvil type in the Yukon have been initiated. This work will focus on the improved understanding of alteration and graphite in the ores, distribution of silver in the ores, and effects on recovery of contained metals. Initial batch-scale metallurgical investigations on such ores indicate resistance to fine grinding and poor recoveries. Liberation studies on the crushed feed and bench test products are being carried out by image analysis.

(c) A detailed study of the occurrence and nature of the platinum-group minerals associated with chromite contained in the lower part of the Chromitiferous Zone in the Bird River Sill, S.E. Manitoba has been initiated. The platinum-group minerals identified to date include sulphides, arsenides and tellurides and occur mostly as inclusions in the silicate minerals and not in chromite. This is in marked contrast to the nature and mode of occurrence of the platinum-group minerals in the Main Chromitiferous Zone.

(d) Mineralogical investigations of rare-element containing deposits in Canada have been initiated. These deposits contain large amounts of such elements as beryllium, zirconium, and the rare-earth elements (e.g. Ce, Y, La, Nd, and Sm).

(e) The study of the effect of arsenic substitution in the sulphur site of the jarosite crystallographic cell upon silver losses into jarosites is continuing. Specifically, the crystal structure of beudantite has been determined. Beudantite, $Pb(Fe,Al)_3[(As,S)O_4]_2(OH)_6$, unlike plumbojarosite, shows no evidence of a doubled cell. There is disorder in the Pb position, and strong evidence that the tetrahedral site is randomly occupied by As and S. The (As,S)-O bond lengths in the tetrahedron bear this out. The significance of this surprising result upon the coordination at the Pb site, where silver is likely to become entrapped, is still being investigated.

(f) Detailed mineralogical investigations of selected gold ores using such techniques as electron microprobe analysis, ion microprobe, and Micro-PIXE have commenced. This work has indicated that the electron microprobe can be used to determine trace levels of gold (>200 ppm) in common sulphide minerals. A more sensitive analytical technique is the ion microprobe and a new analytical method has been developed at Surface Science Western with a sensitivity of <1 ppm.

Contracts:

- Reqn. 5-9209 and 5-9210 MDA "Pt. Leamington deposit, Nfld, Phase I - sampling and Phase II - mineralogy and metallurgical testing", Noranda Research Centre. S.A. - J.L. Jambor.

- Reqn. 5-9216 "Sampling and analysis of New Brunswick manganese deposits", Atlantic Analytical Services. S.A. - G.M. Ritcey.

- Reqn. 5-9217 "Evaluation of options for treating New Brunswick manganese mineral deposits", Witteck Development Inc. S.A. - G.M. Ritcey.

- Reqn. 6-9056 MDA "Wabush Lake, Labrador quartzite", Golder Associates. S.A. - R.K. Collings.

Reports:

- J.H. Jambor, "Detailed mineralogical examination of alteration products in core WA-20 from Waite Amulet tailings"; Division Report MSL 86-137 (IR).

- J.M.D. Wilson, "A mineralogical examination of a calcite sample from Chromasco, Haley, Ontario"; Division Report MSL 86-8 (CR).

- J.M.D. Wilson, "An investigation of gold occurrences in Alberts Lake test products"; Division Report MSL 86-25 (CR).

- J.M.D. Wilson, W. Petruk, "Mineralogical investigation of three ferrosilicon samples from Chromasco, Haley, Ontario"; Division Report MSL 86-8 (CR).

Beneficiation - Metallic

- **Project 30.13.01:** Mineral Processing Plant Simulation (SPOC)
  Project leader : D. Laguitton

Objective:

To provide the technology transfer necessary to improve the recovery and/or value of minerals from the processing of Canadian ores through the application of modelling and simulation of minerals and energy processes by providing the mineral industry with an easily usable computer methodology for circuit evaluation and optimization.

Project Report:

The 1986/87 activities were centered around two areas:

1. Exploitation of microcomputer capabilities of the SPOC software;

2. Structuring and initiation of the post-SPOC activities at CANMET.

The initial conversion of the SPOC software from mainframe to microcomputers of the IBM-PC type had been done in 1985 in order to facilitate transfer of the source code to the mineral industry which had generally adopted this microcomputer as a pseudo-standard machine. Several features initially included in the mainframe version were either useless or cumbersome in

microcomputers where memory space is no longer a restriction but speed is still a problem. The latest code update has addressed this situation and includes a number of friendly features made possible in a personal computer (PC) environment, especially full screen editing of files, graphics, colour coding and others. The simulation of a circuit can be initiated by drawing the network on the screen from a list of available modules retrieved and positioned by the user. The stream numbering is assigned automatically by the system and the stream connection matrix corresponding to the given flowsheet is automatically generated, thus eliminating tedious data entry by the user and allowing the simulation to proceed from a graphic data entry.

The microcomputer version of the software has been upgraded to be compatible with version 3.31 of the MS-DOS FORTRAN compiler. Software and manuals distribution has continued at an increased rate and by the end of 1986 a total of over 120 organizations worldwide had received the SPOC methodology package they had ordered from CANMET.

The R&D activities of the post-SPOC period have been structured and initiated. They consist of a three-sided project labelled CAMP (Computer Aided Mineral Processing). The SPOC related facet will continue to upgrade the various simulation programs and especially to address the material balance of leaching circuits and to attach economic variables in the simulation programs. A second area of activity has been labelled SPEX (Simulation of Process Expertise). It consists of developing expert system methodology for the mineral processing industry. An expert system is a software package that simulates the heuristic reasoning of a domain expert, using a knowledge base where the rules and facts about the particular field of expertise are stored. Two contracts have been awarded for phototype studies, one in a zinc refinery environment (Canada Electrolytic Zinc/Lavalin) and the other in a cement manufacturing environment (Canada Cement Lafarge). The objective is to experiment with commercially available expert system shells and knowledge engineering techniques, in order to capture the art of mineral processing and complement the simulation systems developed in SPOC that contain the science of mineral processing.

The third facet named REX (Real-Time Expertise) will consist of developing process control software tools derived from SPOC and SPEX. No formal activity has been initiated in this area.

Contracts:

- Reqn. 6-9137 "Pilot application of expert system technology to process control", Cosigma Lavalin Inc. S.A. - D. Laguitton.

- Reqn. 6-9149/01-SQ "Development of a prototype expert system in a grinding circuit", Canada Cement Lafarge Ltd. S.A. - D. Laguitton.

Reports:

- D. Laguitton (ed.), SPOC Manual SP85-1/18 Separate titles listed in MSL 85/86 Annual Report.

- D. Laguitton, "New computer technology finds applications in mineral processing R&D at CANMET"; Division Report MSL 87-1 (OP&J).

• Project 30.13.02: Iron Ore Processing
Project leader : W.H. Cameron

Objective:

To maintain the viability and competitiveness of the Canadian iron ore industry by identifying and investigating methods to increase recovery, improve grade and quality of iron ore concentrates and pellets, reduce energy costs, improve process control and lessen environmental impact.

It has become increasingly apparent in an iron ore buyer's market that Canada cannot assume that it can compete in any market. High labour and energy costs have made pellets less attractive than sinter feed for a blast furnace. The Canadian iron ore industry finds itself in a position which is less competitive than formerly. There is a need to improve efficiency, reduce energy costs and improve product quality and recovery.

(a) Cold extruded pellets

Since this method has proven successful using Quebec Cartier Mining, Mount Wright concentrate, it was decided it should be attempted with concentrate from another mine site, the objective being to produce more uniform physical characteristics in the green balls. Work on Carol Lake iron ore concentrate using polymers and calcium carbonate as a plastisizer and binder has been completed. Strength of the indurated pellets was below the I.S.O. specification. However, if the ore is roasted at 750 to 850°C to convert magnetite in the ore to hematite, a substantial improvement in strength (2 to 4 times) in the indurated briquettes occurs, more than sufficient to meet specificaitons.

(b) Pelletizing using inorganic, cold bonding

If successful, pellets made in this manner may be shipped as green balls, without undergoing induration, resulting in huge energy savings. In the presence of carbon dioxide, calcium hydroxide in iron ore reacts to form a basic carbonate which acts as a bond for the iron ore fines. It is believed that the low strength of pellets made from Carol Lake concentrate is due to the fine grained nature of the material which prevents complete penetration of the carbon dioxide to the interior of the pellets. Future work will examine the sinter fines in the mixture to change the size distribution, thereby improving permeability and porosity.

(c) Agglomeration of iron ore using polymers as binders

In an attempt to reduce the silica content in the pellets, and because of

the high costs of bentonite, experiments with other binders are being carried out. Excellent physical characteristics have been obtained in pellets made from Quebec Cartier Mining, Mount Wright ore by adding 0.1 to 0.4 wt % of organic binders such as methycellulose, hydroxyethyl cellulose, carboxy methyl cellulose and alginate.

(d) Iron recovery from spiral tailings

A 1% increase in iron unit recovery can mean $6 million in profit to an iron ore operation. It is therefore important to attempt to recover additional iron units that are lost in tailings. This element was delayed because of late delivery of a new pump and modifications required to a sump box. Preliminary investigations using MDS #7 spiral do not look too promising regarding grade and recovery. Since over 60% of the iron is found in the -0.01 cm fraction, it has been decided to screen the tailings at this size and use selective flocculation followed by a reverse amine float. Since this ore is also high in manganese, it is hoped that the manganese will float along with the gangue minerals.

(e) Mill recovery predictions from blast hole cuttings

This is a common practice carried out by all mines. The methods presently used however are slow and tedious with some actually being hazardous to health. A faster, safer method is therefore a high priority to the industry. Various separation and settling methods were tried unsuccessfully. With the recent acquisition of a Mozley Laboratory Separator, experiments will continue using this equipment in an effort to improve predictions.

(f) Self dewatering concentrates

This phenomenon occurs with some concentrates, during shipping, with the result that the hold of a ship contains an unsalable sludge. A literature survey is underway and experiments have been completed using surfactants and water sequestering agents. Bentonite and peat moss as water sequestering agents have been tried with peat moss showing the most promise. Work is continuing.

(g) Improved recirculated water

Thickener overflow water is used as make-up water in a concentrator, but, particularly during certain periods of the year, is of poor quality creating problems throughout the circuits. A mineralogical examination of water samples was done followed by experiments using cationic, anionic and non-ionic polymers. Settling rates have been significantly enhanced by 2-14 times and the amount of overflow water increased by up to 30%. This was accomplished by the use of an anionic flocculant with additions as low as 85 mg/tonne.

(h) Other activities

Two meetings of the Iron Ore Technical Task Force Committee were held in Wabush, Labrador, on September 23, 1986 and in Ottawa on January 23, 1987 to discuss problems common to the industry.

Contracts:

- Reqn. 4-9181 "Comparative study of geostatistical grade control and classical approach - iron ore processing", Geostat Systems Int. Inc. S.A. - W.H. Cameron.

- Reqn. 4-9316 MDA "Development of a technically and economically acceptable substitute binder for bentonite for use with Carol Lake concentrate". S.A. - M.D. Wilson.

- Reqn. 5-9196 MDA "Increase of iron ore recovery". S.A. - M. Stefanski

- Reqn. 6-9145 MDA "To improve iron ore recovery at the Scully Mine, Labrador, Phase II and III". S.A. - M. Stefansky.

- Reqn. 6-9171 MDA "Evaluation of the Bass River Nova Scotia magnetite deposit for Lodestone Limited". S.A. - W.H. Cameron.

- Reqn. 6-9187 MDA "Iron ore binders, Part 2". S.A. - J.M.D. Wilson.

Reports:

- W.H. Cameron, "Algoma ore division - densimetric curves"; Division Report MSL 86-1 (CR).

- A.K. Kuriakose and D.H.H. Quon, "Extrusion and induration of Carol Lake concentrate using polymers and calcium carbonate for bonding"; Division Report MSL 86-136 (IR).

- A.K. Kuriakose, D.H.H. Quon, K.E. Bell and J.A. Soles, "Extrusion and induration of iron ore using polymers and calcium carbonate as plastisizer/bond"; Division Report MSL 86-13 (OP&J).

- M. Silver, V. Sanmugasunderam and R.G.L. McCready, "The role of bacteria in the formation of organic deposits on the spiral concentrators of the Mount Wright Plant, Quebec Cartier Mining Company"; Division Report MSL 86-152 (OP&J).

• Project 30.13.03: Design, Development, Evaluation and Commissioning of Scientific Equipment
Project leader : A.I. Stemerowicz

Objective:

To design, fabricate and test Continuous Process Development Unit (CPDU) equipment not available commercially; to test and evaluate the performance of equipment for mineral processing and to compare the performance of alternative equipment designs; and to commission other scientific equipment purchased for CANMET's laboratories.

(a) Industrial minerals mill

This project as it applies to the industrial minerals mill is being carried out in conjunction with other R&D projects. The following equipment was evaluated and commissioned.

(i) Micromeritics Sedigraph 5000D

This unit is on a fully operational basis and can perform well on single-mineral samples or on multi-minerals samples provided care is exercised. The unit was found sensitive to large differences in specific gravities of the constituent minerals in samples, including magnetic minerals.

(ii) Walther air classifier

Different components of the unit were modified in order to reduce contamination and to increase the stability of the air flow rate.

(iii) Zig-Zag classifier

The unit is now operational and can perform separations based on the size and density of constituent mineral particles. The efficiency of separation was found to follow Stoke's law rather than a turbulent flow relationship, and for this reason, the unit is useful in separating minerals specifically when the shape faction of one mineral is irregular (i.e., asbestos, micas). The enclosed nature of the unit was found to be particularly applicable for treating fine, dusty or hazardous mineral samples.

(b) Mineralogy

(i) Automated powder diffractometer

A new Rigaku Automated Powder Diffractometer (APD) has been installed in the X-ray Laboratory, Room 222, 555 Booth Street. This instrument is powered by a 12kW rotating-anode X-ray generator, and has both a standard powder diffractometer and a micro-diffractometer for examination of very small specimens. There are still problems with the functioning of some of the software, but when full developed, the instrument will be able to do large numbers of qualitative and quantitative analyses by means of X-ray powder diffraction. The APD is equipped with a sample changer for sequential examination of up to 43 specimens. Control of the instrument is achieved

with a micro-PDP11/73 computer with a 30 megabyte disk containing the powder-diffraction library of the Joint Committee for Powder Diffraction Standards (JCPDS) for phase identification. The work station consists of a Tektronix 4106A colour terminal with a Tektronix 4695 ink-jet plotter. Different powder-diffraction patterns can be examined simultaneously, and matched phases from the JCPDS Library or from a user-generated library can be plotted on the X-ray powder profile in up to 5 colours.

(ii) Proton microprobe

Collaboration on development of Canada's first proton microprobe at University of Guelph has continued successfully during the past year. All necessary parts have been designed, ordered, are under construction or nearing completion (magnetic elements for beam steering, electronic control systems, target chamber including sample stage, microprobe lenses and slit systems). Hopefully, the first tests can be run in the fall.

Contracts:

- Reqn. 5-9230 MDA "Evaluation of equipment and process to sample offshore placer deposits from small fishing vessels", Nordco Limited. The project has been completed and the data are being analysed prior to issuing a RFP for Phase 3 in which a sampling system and program would be designed. S.A. - D.M. Doyle.

• Project 30.13.04: Improved Recovery Technology of Fine Particles and Tin
Project leader : M.A. Cristovici

Objective:

To investigate methods to improve the recovery of fine mineral particles and to develop methods to improve the recovery of tin from base metal sulphide flotation tailings.

(a) Selective flocculation of tantalum ore

A tantalum ore sample was chosen to study the possibility of separating mineral particles in the fine size range by selective flocculation.

After completion of physico-chemical determinations carried out to characterize the mineralization and particle size distribution, research work was initiated to evaluate the conditions for minerals separation by selective flocculation.

The following mineralogical constituents of the ore were isolated: woolginite and microlite (both tantalum oxides) cassiterite (tin oxide) and gangue minerals (feldspar and quartz). In order to achieve selective flocculation, the heterocoagulation of these minerals must be avoided and

the maximum stability of the minerals in suspension must be achieved. To study the conditions for a stable suspension, Zeta potential determinations were performed at various pH values. These tests were carried out for each mineral group on their own as well as in the presence of supernatant containing the other dissolved species. From Figure 1 it can be seen that a stable suspension can be obtained at pH > 10, where the Zeta potential of the particles is of the same sign and the difference between the electric charges of tantalum-cassiterite and gangue minerals tends to increase.

The work is continuing with selection of dispersants that will enhance the suspension stability. The selective flocculation will then be tried using various flocculants.

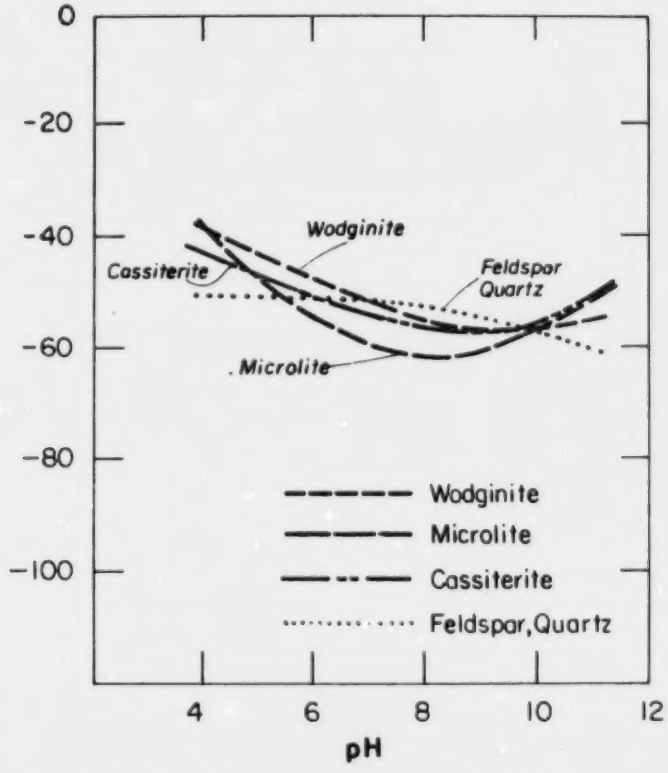

Fig. 1. Zeta potential of the minerals in the presence of dissolved species

(b) Micro-bubble flotation

A few flotation tests were conducted on the minus 0.2 cm portion of a finely ground massive sulphide (copper) ore using a venturi-type microfoam generator as the flotation device. Results were negative; flotation rates were unacceptably low. Although a fine cloud of bubbles of < 50 µm in diameter was produced, there was a great deal of bubble coalescence such that the final flotation was composed of bubbles of normal size (about ±2 to

-10 mm diameter). Thus the advantage of the high surface area of the tiny bubbles could not be utilized. Calculation showed that a 50 µm bubble of air fully armoured with 5 µm chalcopyrite would have the same density as water and, therefore, would not be buoyant enough for effective flotation. The result was a tendency for the tiny bubbles to coalesce until the much larger armoured bubble is buoyant enough for flotation. From this it was concluded that micro-bubble flotation would only be suitable for particles smaller than 5 µm.

(c) Reduction of SnO_2 to tin at cassiterite surface

The objective is to make cassiterite amenable to recovery by flotation using sulphide collectors such as amyl xanthate. First, it was established that amyl xanthate is an effective collector for fine metallic tin powder. Two tin reduction methods were then tried on Kidd Creek gravity tin concentrate: (i) Cathodic reduction in HCl solution with metallic zinc as anode. (ii) Reduction by nascent hydrogen produced by electrolysis in an electroflotation cell. Results were negative as measured by the lack of flotation response of cassiterite. The failure of method (i) is attributed to the fact that Kidd Creek cassiterite is not a semi-conductor while method (ii) probably requires elevated temperatures. During the testing, it was found that the electrodes did not evolve a sufficient quantity of hydrogen gas to support normal rates of flotation. Therefore, a new electroflotation cell will have to be devised with much higher electrode surface area and fabricated from plastic that can withstand boiling water temperature (the present cell is fabricated from acrylic).

(d) Tin flotation using new developed reagents

Testwork has been initiated to recover tin minerals from Kidd Creek tailings using new developed reagents and Nagahm flotation machine. Prior to tin flotation, experiments were carried out to remove the sulphide minerals present in the tailings, mainly pyrite and sphalerite. Over 70% of the sulphides were removed by floating the tailing in the as-received state using a conventional Denver cell. Then the ore was ground to almost 100% - 38 µm and the rest of the sulphides were floated away in the Nagahm cell.

The Nagahm flotation machine (Figure 2) has a special rotor configuration that produces an intense agitation and large amount of fine air bubbles well dispersed in the slurry.

The removal of sulphides has been achieved and now research work is in progress to recover the tin minerals. Among the reagents intended to be used are a dispersant (proestaminol; produced by Stockhousen) and an amino-phosphonic acid (Briquert; manufactured by Albright and Wilson House).

Contracts:

- Reqn. 5-9030 MDA "To develop S reducing mineral beneficiation techniques and perform S emission tests at Inco Smelter, Thompson, Manitoba", Inco Ltd. S.A. - W. Craigen.

- Reqn. 6-9012 MDA "Column flotation - cleaning of zinc rougher and scavenger concentrate", Sherritt Gordon Co. S.A. - K.S. Moon.

- Reqn. 6-9062 "Characterization and application of new organic depressants for the selective flotation of sulphide ores", Lakefield Research. S.A. - A.I. Stemerowicz.

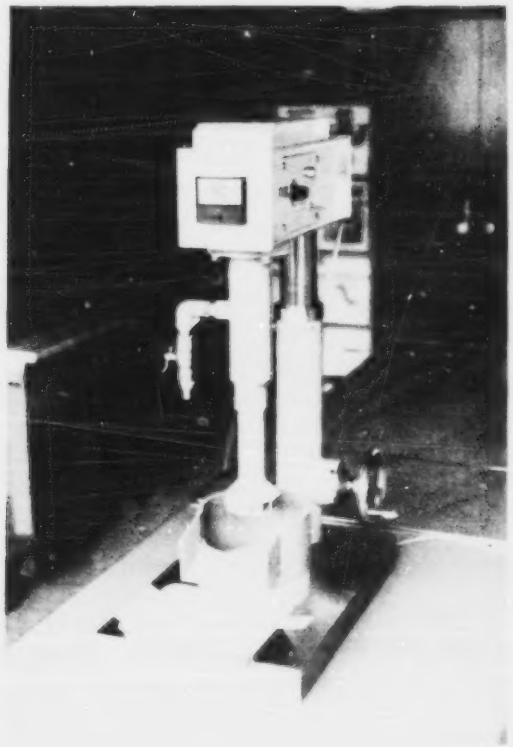

Fig. 2. Nagahm flotation cell

- **Project 30.13.05:** Liberation/Flotation Models
  Project leader : W. Petruk

Objective:

To develop a liberation model which predicts the mineral liberation that would be obtained at different grinds for different ore types, and to incorporate the predictive model into grinding and flotation models which have been developed at CANMET by the SPOC Program. Several liberation models, based on size distributions of minerals in unbroken ores, have been proposed, but in many instances the predicted liberation does not correspond

to observed liberation. It is therefore necessary to determine the fundamental properties that effect liberation before a model can be developed.

It was found during the early stages of the investigation that by using the Finch and Petruk (1984) liberation model there is a close correlation between the observed and predicted liberation for sphalerite from base metal ores (Petruk, 1987) but not for chalcopyrite and galena. Subsequent work has indicated that the reason for the above observation is that the sphalerite in the ore tested occurs largely as separate grains, hence its liberation can be predicted from grain size distribution of sphalerite in the unbroken ore. By contrast, the chalcopyrite and galena occur largely in interstices in pyrite; therefore, their liberation is controlled by the breakage of pyrite.

A study was conducted by (1) determining the size distributions of pyrite, sphalerite, galena and chalcopyrite in an unbroken base metal ore, (2) grinding the ore for different lengths of time, and (3) determining liberation characteristics and size distributions of the particles in the ground products. It was found that the screen analysis for the 15 minute grind corresponds to the size distribution of the pyrite in the ore. Breaks in the screen analysis curves for the 30, 45, 60 and 90 minute grinds correspond to changes in textures of the pyrite as defined by a perimeter/erosion analysis technique with the image analyser. The perimeter/erosion analysis texture of the interstitial minerals in pyrite corresponds to the texture of the pyrite. Liberation of the interstitial minerals occurs when the pyrite textures are destroyed by grinding.

The findings were correlated with the operation of a concentrator for one base metal ore. It was found that the screen analysis of the flotation feed corresponds closely to the size distribution of the pyrite in the unbroken ore (equivalent to 15 minute grind). This indicates that an ore tends to break along zones of weakness and along pyrite grain boundaries, and it comes to equilibrium when weakly cemented pyrite grain boundaries are broken. Mill operators tend to grind an ore until it reaches this equilibrium. At this stage the interconnected interstices in pyrite have been destroyed, and the interstitial minerals are either liberated or attached to pyrite as middlings. Further grinding will break the middlings from the pyrite and will separate moderately cemented pyrite grains (equivalent to 30 to 60 minute grinds). The amount of energy required to achieve this is high in porportion to the additional liberation obtained. Further grinding (equivalent to 90 minute grind) produces breakage across grains. It does not achieve much size reduction nor liberation.

Contracts:

- Reqn. 4-9232 MDA "Mineralogical studies of potash deposits", New Brunswick Researach and Productivity Council. S.A. - W. Petruk.

- Reqn. 4-9235 MDA "To determine mineralogical characteristics that affect

the behaviour of copper, zinc, lead, silver and gold in copper, zinc and lead concentrates from Cu/Zn/Pb ores in Manitoba, Phase (1a) Mineralogical characteristics of Trout Lake ore, Phase (1b) Behaviour of Trout Lake ore during beneficiation", Hudson Bay Mining and Smelting Co. S.A. - W. Petruk.

Publications:

- J.A. Finch and W. Petruk, "Testing a solution to King liberation model"; Int J Mineral Processing 12:305-311; 1984.

- W. Petruk, "Predicting mineral liberations in ores and mill products and effect of mineral textures and grinding methods on mineral liberation"; Process Mineralogy VI, AIME, New York; 1987.

Beneficiation - Industrial Minerals

- Project 30.21.01: Energy Conservation in Industrial Mineral Processing
  Project leader : F.R. Campbell

Objective:

To increase the energy efficiency of existing industrial systems and to develop technologies to reduce the energy content per unit of production in the industrial mineral sector.

The industrial minerals sector spends more money on energy as a production input than any other industry, nearly four times the average for the manufacturing sector as a whole. In certain industries, such as cement, lime and gypsum, energy costs represent about one half of production costs. While the situation has improved somewhat since the days of cheap oil, further improvements require improved equipment design, process modification, fuel switching, use of less energy intensive materials as supplements and the optimization of energy flows. All of these require R&D to optimize processing conditions.

This project includes work in three main areas: a) comminution, b) firing of clay products, and c) use of supplementary cementitious materials in concrete.

This program is supported largely through the federal energy R&D program under the Panel on Energy R&D. Most of the work is being carried out under contract although some work under c) involving the use of ferrous and non-ferrous slags is undertaken in-house.

(a) Comminution

Reducing the size of the as-mined materials to meet processing or end use

requirements represents the major component of energy input in the processing of many industrial minerals. This element of energy and dollar cost can be reduced through improved grinding techniques plus much closer control of the degree of grinding.

Earlier phases of this project developed a data base on current comminution methods for 10 common industrial minerals, and established a monitoring methodology for control of comminution circuits. Phase III got underway during 1985/86 and will develop, on the basis of pilot-plant tests, a detailed statement of technical requirements for implementing state-of-the-art comminution technology in the Canadian minerals processing industry. This phase will be completed in 1988 and will be followed by a demonstration, probably in a cement plant.

The project includes the following elements:

i) evaluation of classifiers
ii) use of grinding aids
iii) use of on-stream particle size analysers
iv) wet comminution of asbestos
v) autogenous grinding of quartzite
vi) mica comminution

Of these, the first four are now complete. The results indicate that classifiers, on-stream particle size analysis and grinding aids could reduce comminution energy costs substantially and increase throughput by as much as 100% in certain industrial mineral plants.

(b) Firing of clay products

The firing of clay products is a high temperature industrial process which utilizes large amounts of energy. Improvements which increase the thermal efficiency of this process or reduce the firing temperature or time can result in substantial energy savings.

The use of scrubbers to control fluoride emissions on existing kilns reduces the thermal efficiency of the kiln's heating process. The initial phase of this study identified different firing schedules and/or additives which could reduce fluoride emissions without scrubbers. However, when tested with a variety of clays in a variety of kilns, neither approach showed itself to be generally effective. Nonetheless, during testing it was noted that bricks in the cooler regions of the kiln were "gettering" fluoride from the hot regions. In discussions with the Clay Brick Manufacturers Assn., a further phase has been suggested to investigate the effect of recyling the fluoride rich effluent through cooler kiln areas.

(c) Supplemetary cementing materials (see also project 30.37.01)

The manufacture of cement is especially energy intensive (grinding and calcining). A number of largely waste materials (fly ash, condensed silica

fume, ferrous and non-ferrous slags) can substitute in part (up to 50%) for the cement in many concrete applications without major processing requirements. This program seeks to develop and demonstrate such supplementary cement materials (SCM). The majority of the work is contracted but in-house studies have examined the physical characteristics of the supplements and of the resultant concretes.

In addition to their other advantages, some SCM's can reduce the deleterious effect of alkali-aggregate reactivity. This study is examining the effect of a range of additions of a number of SCM's on a variety of aggregates known to be reactive. While the longer term testing is not yet complete, results to date are very encouraging.

A process has been developed and a production facility built to produce a desirable SCM from blast furnace slag. The product slags and concretes made from substituting this slag for varying amounts of cement have been subjected to round robin testing.

Blast furnace slags from the production facility at Sault Ste. Marie are being tested by one independent laboratory and a number of mining companies as a cementitious additive to mine tailings to make mine backfill.

Contracts:

- Reqn. 2-9200 "Utilization of Canadian pozzolanic materials in reducing the effects of alkali-aggregate reactivity", Canada Cement Lafarge. S.A. - J.A. Soles.

- Reqn. 3-9227 "Production and evaluation of blast furnace slag from Algoma Steel's furnace for possible use as an additive to concrete", W.M. Watts Engineering Limited. S.A. - V.M. Malhotra.

- Reqn. 4-9037 "Energy conservation by chemical comminution of asbestos Phase II", Ontario Research Foundation. S.A. - D.M. Doyle.

- Reqn. 4-9263 "Energy conservation in comminution of Industrial Minerals Phase III: Development of pilot-plant systems", Canada Cement Lafarge Limited. S.A. - D.M. Doyle/T. Cienski.

- Reqn. 5-9117 "Effect of fluoride emission controls on the energy efficiency of tunnel kilns manufacturing structural clay products Phase IIB, Pollutech Limited. S.A. - K.E. Bell/A.K. Kuriakose.

- Reqn. 5-9186 "Energy conservation in investment casting using Canadian industrial minerals Phase II", Designed Precision Castings Inc. S.A. - K.E. Bell/A.K. Kuriakose.

- Reqn. 6-9156 "Evaluation of blast furnace slag as an additive to mine backfill", W.M. Watts Engineering Limited. S.A. - E. Douglas.

- **Project 30.21.02:** Beneficiation/Grinding Studies of Selected Minerals
  Project leader : R.K. Collings

Objective:

To develop and improve processing methods for the recovery of minerals and mineral products, acceptable to specific markets, from selected industrial mineral deposits, and including improved methods for the production and classification of ultra-fine mineral materials for specific applications, notably the filler/extender market.

Concern by both government and industry regarding present and future resources of industrial minerals, increased exploration, development, processing and energy costs, more stringent product specifications, more diverse and developing applications and markets, and competition in and for these markets, have focussed attention on the need for more information on our resources and their potential for development, for more efficiency in production and processing, and for greater diversity in product development to maintain a competitive edge in domestic and international markets. This project has been developed in response to this concern. Work in progress during the review period includes studies on silica, barite, potash, kaolin, asbestos, and on fine grinding and classification of minerals.

(a) Silica

Phase III (Newfoundland, Nova Scotia, New Brunswick, Manitoba, Saskatchewan and British Columbia) of the Canadian Silica Resources project was completed and a report issued. A summary of all three phases (Phase I, Ontario; Phase II, Quebec; Phase III Newfoundland, Nova Scotia, New Brunswick, Manitoba, Saskatchewan and British Columbia) is in preparation.

(b) Barite, celestite, fluorite

A summary report is being prepared of past and present studies by CANMET on these three minerals. The report will be supplemented by descriptions of deposits, occurrences, past mining operations and the present situation with regard to each mineral.

Laboratory studies undertaken in connection with the Canada/Nova Scotia Mineral Development Agreement on samples of barite from Scotsville, Lake Ainslie, Pine Brook and Brookfield, demonstrated good potential for the recovery of mud-grade (S.G. = 4.2) barite by gravity separation methods coupled, in the case of the Brookfield sample, with wet magnetic separation.

(c) Kaolin

Further detailed flotation evaluation of the Black Island kaolin deposit is being conducted to establish parameters for the production of paper grade kaolin. A report will be prepared on completion of the work.

(d) Potash

Selective flotation of potash from common salt in K-saturated and Na-undersaturated salt solution is being considered for the improvement of flotation efficiency. Triflo heavy medium separation studies indicated that this process is a good substitute for the existing flotation for separating insol from the two salts. Dry magnetic separation studies with high-intensity, high-gradient (2 tesla) permroll magnetic separators have proven to be very successful in removing the paramagnetic insol materials from sylvite and halite. The dry electrostatic separation of sylvite from halite is being studied with some improved selectivity following modification of the surface charge of the salts using octanoic acids.

(e) Graphite

Background information of deposits and of processing of graphite were reviewed. The provinces also were contacted for information and research on potential deposits. Gravimetric and flotation separation techniques were investigated using selected graphite samples.

(f) Mica

A typical miscovite-rich schist was examined and the mica concentrated successfully using a combination of air table, zig-zag classifier and permanent magnet separator.

(g) Bentonite

Background information of deposits and beneficiation studies were reviewed and test equipment assembled and commissioned using various bentonites.

(h) Asbestos

A contract to investigate the chemical defibrization of asbestos fibre showed that chemicals assisted in opening of fibres; however, these surfactants could not be economically removed - a necessary requirement for acceptance in asbestos cement applications. Studies at Cassiar Asbestos in northern British Columbia on the wet processing of asbestos are continuing. The company has developed a wet asbestos process using CANMET technology and is mid-way through a $1.2M PILP agreement. Fibre produced from tailings has extremely low fines content and capital and operating cost studies indicate a wet process would operate with 40% lower capital and operating costs. The pilot plant continues to operate, currently evaluating various equipment for fibre grading, water recycling, and fibre characterization, and currently producing samples for customer evaluation.

(i) Fine grinding/sizing

Work continued re grinding/classifying of talc/calcite/quartz (hardness 1/3.5/7) samples with a Sturtevant jet mill and Hardinge air classifier. A

report of this work is in preparation.
Contracts:

- Reqn. 4-9232 MDA, "Mineralogical studies of potash deposits", R.P.C. New Brunswick. S.A. - W. Petruk.

- Reqn. 5-9079 MDA, "Laboratory and pilot plant study on electrostatic separation of potash ore", Potash Corportion of Saskatchewan. S.A. - K. S. Moon.

- Reqn. 5-9245 MDA, "Mineral processing investigations of Bird River chromite ore", Lakefield Research Canada Limited. S.A. - P. R. A. Andrews.

- Reqn. 5-9246 MDA, "Upgrading of feldspar", Tantalum Mining Corporation. S.A. - P. R. A. Andrews.

- Reqn. 5-9250 MDA, "Manitoba slag study", John Emery Geotechnical Engineering. S.A. - S. S. B. Wang.

- Reqn. 6-9031 MDA, "Laboratory and pilot-plant studies of Nova Scotia celestite", Chromasco Limited. S.A. - R. K. Collings.

- Reqn. 6-9083 MDA, "Pine Brook barite, Cape Breton, Nova Scotia", Technical University of Nova Scotia. S.A. - R. K. Collings.

- Reqn. 6-9119 MDA, "Dry magnetic separation of insol from sylvite and halite", Central Canada Potash of Noranda. S.A. - K. S. Moon.

- Reqn. 6-9122 MDA, "Offshore product quality", Potash Corp. of Saskatchewan. S.A. - E. Joe.

- Reqn. 6-9123 MDA, "Dense medium separation of potash ore using triflo dense medium separators", Potash Cominico Limited. S.A. - K. S. Moon.

- Reqn. 6-9147 MDA, "Prefeasibility study on the economics of the Bird River chromite deposits, Phase III". S.A. - P. Andrews.

- Reqn. 6-9163 MDA, "Preparation and evaluation of certain N.S. industrial minerals for use in fillers, extenders and chemicals", Magstone Development Inc. S.A. - R. K. Collings.

Reports:

- P.R.A. Andrews, "Beneficiation of a sample of silica from Sussex, N.B."; Division Report MSL 86-2 (IR).

- P.R.A. Andrews, "Evaluation of a sample of kaolin from Black Island, Manitoba"; Division Report MSL 86-79 (IR).

- P.R.A. Andrews, "Beneficiation of nephaline syenite from British Columbia; Division Report MSL 86-88 (IR).

- P.R.A. Andrews, J.M. Lamothe, and S.S.B. Wang, "An evaluation of Kipp Kelly air table"; Division Report MSL 86-149 (TR).

- P.R.A. Andrews, and L. Morin, "An evaluation of a mozley cyclone"; Division Report MSL 86-147 (IR).

- R.K. Collings, P.R.A. Andrews, "Canadian silica resources: A study of the processing of Selected Silica Samples from Nova Scotia, New Brunswick, Manitoba, Saskatchewan and British Columbia for glass and foundry sand"; Division Report MSL 86-50 (IR).

- R.K. Collings, J.M. Lamothe, S.S.B. Wang, P.R.A. Andrews, "A study of the processing of barite samples from selected deposits in Nova Scotia"; Division Report MSL 86-95 (IR).

- J.M. Lamothe, and S.S.B. Wang, "Beneficiation of vermizulite samples from Stanleyville, Ont"; Division Report MSL 86-18 (IR).

- S.S.B., Wang, and R.K., Collings, "Beneficiation of rock salt samples from Pugwash, N.S."; Division Report MSL 86-86 (IR).

Treatment - Ceramics

- Project 30.29.01: Preparation and Characterization of Advanced Ceramic Materials
  Project leader : T.A. Wheat

Objective:

To develop the technology for the fabrication and exploitation of various advanced ceramics for both structural and functional applications and to demonstrate their promising applications through technology transfer.

This project reflects the growing international interest in the use of ceramic materials for functional (e.g. electrical) and structural applications. Some of the functional uses are in sensors of various kinds, NDT transducers, batteries, ion pumps and fuel cells. Structural applications are based on toughened, wear-resistant, corrosion resistant and high-temperature, high-strength ceramics for uses such as ultra-high-temperature gas turbines, internal combustion engine parts, heat exchangers, cutting tools and contact bearings.

(a) Development of beta"-aluminas for use in energy storage and conversion

Work on this project element was directed to optimizing the processing and

compositional parameters for the fabrication of beta/beta"-aluminas containing Li^+ and Mg^{2+} stabilizer and also to initiate methods for the preparation of beta/beta"-alumina toughened by zirconia. Characterization of the products is under way.

(b) Development of isotropic hydrogen conductors

In order to establish optimum compositions for the isotropic hydrogen conducting zirpsics (Nasicons), a number of hydronium zirpsios samples (>250) were prepared and bonded by the proprietary process reported during the previous year, and characterized. The resultant product is being tested at Atomic Energy of Canada Ltd. Chalk River for applications involving hydrogen conductors. A market survey has indicated that the material has potential in devices for hydrogen sensing. The material has been demonstrated in-house in cells used as hydrogen sensors, hydrogen pumps and hydrogen-air fuel cells of low power.

(c) Development of piezoelectrics for NDT transducers

The development of techniques to detect small sub-surface flaws in sintered ceramic is important if the material is to be stressed electrically and/or mechanically. During the present period, development has continued under contract to BM Hi-Tech Inc., Collingwood in collaboration with McMaster University to lower the limit of detection of fine defects in ceramic using ultrasonic techniques. Commercial transducers can detect ~75 micrometer defects; using custom-made transducers produced under CANMET contract ~25 micrometre defects can now be detected. During the present period, the ability to produce transducers operating over 75 MHz with a focussed beam of any focal length has been developed and used to characterize ceramic microstructure.

A number of doped lead titanate materials have been prepared and characterized for NDT applications. Optimization of the product compositions is in progress.

(d) Development and demonstration of a small-scale commercial thermo-electric generator

This four-year program, completed in March 1986, was conducted by Almax Industries Ltd. under the PILP program with assistance from CANMET to demonstrate a small-scale thermoelectric generator producing electric power directly from any heat source such as an industrial stack. Interest in using these devices for remote power sources has been expressed ranging from the cathodic protection of trans-continental gas pipe lines to space applications.

(e) Development of tough ceramics

Although ceramics generally have high strength and wear resistance, one of their limitations is brittleness. One of the techniques that has a

potential to overcome this problem is to increase their fracture toughness by incorporation of zirconia.

A program has been initiated for the investigation of zirconia-toughened ceramics for structural applications. This work is conducted both in-house and under contract to Electrofuel Manufacturing Company, Toronto. Several compositions of zirconia-toughened alpha-alumina have been prepared in-house by spray-drying of a variety of starting materials. Characterization of the products is under way.

(f) Synthesis of silicon carbide

Silicon carbide is a material that has application in both functional and structural applications. Its semi-conducting character makes it electrically active and its high-temperature strength, oxidation and thermal shock resistance make it one of the few candidate materials for high-temperature, high-stress applications such as in ultra-high-temperature gas turbines and internal combustion engines.

A program has been started for the synthesis of Silicon Carbide of required characteristics for various applications. Substantial industrial interest is indicated in this material and industrial participation is expected.

(g) Development of equipment to determine electrical properties of materials

A system has been assembled for the electrical characterization of materials as a function of temperature and frequency; another system has been assembled for the dc transient response analysis of electrochemical cells. Software for data acquisition and storage for these systems has been developed.

(h) Technical support given other departments funding R&D in ceramics

Because of CANMET expertise, technical advice as a scientific authority has been given to various sectors of EMR and NRC for the following contracts dealing with solid electrolytes:

- Determination of Concentration of Zinc in Liquid Lead and Liquid Silver University of New Brunswick	T.A. Wheat NRC, PRAI
- Superionic Conduction in Bismuth Oxide University of Western Ontario.	A.K. Kuriakose EMR, RAP
- Development of Sodium/Sulphur Battery Powerlex Technologies, Markham.	T.A. Wheat NRC, IRAP

and also in other areas of advanced ceramic developments:

- The Toughening and Strengthening of High Performance Ceramics by Tailored Beta-alumina Second-phase Dispersion McMaster University, Hamilton. — A.K. Kuriakose, EMR, RAP

- Hermetic Seal Technology Quality Hermetics, Toronto. — T.A. Wheat, NRC, IRAP

- Microwave Ceramics Almax Industries, Lindsay. — A. Ahmad, NRC, IRAP

- Ultrasonic Transducers & Materials BM Hi-Tech, Collingwood. — T.A. Wheat, NRC, IRAP

- Sodium-Sulphur Battery Development Powerplex Technologies, Markham. — T.A. Wheat, EMR, IERD

Contracts:

- DSS 03SQ.23440-4-9223 "Characterization of thin films used as electrodes in electrochemical devices", Ontario Research Foundation, Mississauga. S.A. - T.A. Wheat/J.D. Canaday.

- DSS 14SQ.23440-5-9212 "Plasma sprayed perovskite material for electrochemical cell electrodes", Technical University of Nova Scotia. S.A. - J.D. Canaday/A. Ahmad.

- DSS 06SQ.23440-5-9226 "Development of advanced ceramic composites based on boron nitride fibres", The Electrofuel Manufacturing Company, Toronto. S.A. - T.A. Wheat.
- DSS 06SQ.23400-6-9100 "Development of tough ceramics", The Electrofuel Manufacturing Company, Toronto. S.A. - A.K. Kuriakose.

- DSS 15SQ.23440-6-9102 "High resolution ultrasonic transducers for nondestructive evaluation", BM Hi-Tech Inc., Collingwood. S.A. - T.A. Wheat.

- DSS 04SQ.23440-6-9144 "Analytical interpretation of protonic solid electrolyte/electrode polarization on devices", The Electrofuel Manufacturing Company, Toronto. S.A. - J.D. Canaday/A.K. Kuriakose.

Reports:

- A. Ahmad, A.K. Kuriakose, T.A. Wheat and J.D. Canaday, "Physical characteristics of Na and (Na-K), Beta/beta"-aluminas"; Division Report MSL 86-156 (IR).

- J.D. Canaday, A.K. Kuriakose, T.A. Wheat and A. Ahmad, "Electrochemical aspects of protonic solid electrolyte cells"; Division Report MSL 87-30 (OP&J).

- J.D. Canaday, A.K. Kuriakose, T.A. Wheat and A. Ahmad, "Electrochemical cell electrode materials and performance"; Division Report MSL 86-156 (IR).

- A.K. Kuriakose, T.A. Wheat and A.J. Hanson, "Synthesis of silicon carbide"; Division Report MSL 87-28 (OP).

- T.A. Wheat, "Advanced ceramics in Canada"; Division Report MSL 86-64 (OP).

- T.A. Wheat, "Ceramics mission to Japan - March 1986"; Division Report MSL 86-73 (IR).

- T.A. Wheat, "Advanced ceramics in Japan and Canada"; Division Report MSL 86-74 (OP).

- T.A. Wheat, "Advanced ceramics - Japan today and Canada tomorrow"; Division Report MSL 86-84 (OP).

• **Project 30.29.03:** Semiconductor Materials for Photoelectrochemical and Catalytic Processes
Project leader : S.M. Ahmed

Objective:

To develop semiconductor catalysts and photochemical processes with novel applications: (1) photocatalytic oxidation and removal of pollutants such as CN^-, S_2O_3, SO_3^{2-}, $S_2O_3^{2-}$ and H_2S. (2) photoelectrochemical leaching of minerals and photochemical activation of minerals for flotation.

(a) Semiconductor electrode materials

Studies of the photoelectrochemical and photocatalytic properties of specular hematite electrodes in various forms were completed. These studies consisted of photocurrent and impedance measurements, photocurrent spectrum and efficiency measurements, and studies of surface states and traps and photooxidation of reducing agents such as pyrogallol and oxalic acid. Possibilities of using α-Fe_2O_3 semiconductors in electrode or in powder form for photocatalytic processes were examined with recommendations. Two papers are in preparation.

The photoluminescence resulting from radiative recombinations of the photoexcited carriers in GaAs electrodes, with and without cobalt films, was investigated using a He-Ne c-w laser. The field dependence of the luminescence was also investigated under a potentiostatic field and the effect of charge transfer between GaAs and a ferro/ferricyanide redox couple, under illumination, was also observed. This work is among the first of its kind and provides considerable knowledge on electron/hole separation

and recombination, its field dependence and the effect of any trapping centres and surface states, and on the charge transfer processes at the semiconductor-solution interface. The method also provides a technique for studying photochemical and photoelectrochemical dissolution of semi-conductor minerals. Two papers are in preparation.

Screenprinted TiO_2 films of special composition on ceramic plates are being fabricated. These films will be rendered semiconducting subsequently and used for studying photoelectrochemical and redox processes of interest (see below).

TiO_2 powders in the semiconducting form are in preparation, with sites covered with noble metal such as platinum. These will be used as photocatalysts.

(b) Photochemical and photoelectrochemical processes

(i) Destruction of pollutants

Semiconducting TiO_2 electrodes and powders will be used for (1) preparation of H_2O_2, (2) oxidation and removal of CN^-, H_2S, $S_2O_3^{2-}$, SO_3^{2-}, etc., and SO_3, etc. and possibly many chloro-organic pollutants. Experimental work has already begun. Much of the work on H_2O_2 production has been completed and published.

The Renewable Energy Branch of Energy, Mines and Resources is supporting a contract with Solarchem Research, Willowdale, Ont. for "Solar Photochemical Production of Hydrogen Peroxide". This work is of direct interest to CANMET for the H_2O_2 destruction of CN^-. S.M. Ahmed is serving as a consultant and S.A. to this contract. The first phase will be ending in March 1987.

Another prospective contract on destruction of pollutants, where MSL expertise is being made available, is with Nutech Energy Systems Inc., London, Ont. Catalytic oxidation of chloro-organics, such as chlorophenol, on semiconducting TiO_2 is being pursued.

(ii) Mineral processing applications

The effect of semiconducting properties of SnO_2 on its flotation has been investigated and the report is in preparation. Preliminary work on photochemical leaching of New Brunswick complex sulphide ore has shown that except for Pb, leaching of all other semiconducting minerals, and of Ag in particualr, is significantly increased. More elaborate work is being planned in this direction.

(c) IEA program

Canada has participated for the past six years in the International Energy Agency (IEA) program of research and development for the production of

hydrogen by photocatalytic electrolysis of water using solar energy (Task VI). During this period CANMET's work has been contributed as Canada's contribution, and in return Canada shared information from several other countries. This program was formally terminated in October 1986. The technology developed and acquired during the program is now being applied in a number of areas. A final report of the Canadian contributions to the IEA Task VI has been published recently in Int. J. Hydrogen Energy, 12 (1987) 23. A final report from the IEA Task VI Operating Agent has also been received and is available.

Contract:

- Reqn. 3-9114 "Investigation of semiconductor catalysts for the production of liquid fuels", S.R. Morrison, Simon Fraser University, Burnaby, B.C. S.A. - S. M. Ahmad.

Reports:

- S.M. Ahmed, "The Canadian contribution to the I.E.A. work on photoelectrolysis of water; Division Report MSL 86-53 (OP&J).

- S.M. Ahmed, "Canadian contribution to IEA, Task IV, production of hydrogen by photocatalytic water electrolysis - 1985"; Division Report MSL 86-4 (TR).

- S.M. Ahmed, J. Leduc and S.F. Haller, "Studies of the photoelectrolytic behaviour of specular hematite"; Division Report MSL 86-53 (OP&J).

- Project 30.29.05: Electrodes and Refractories for the Steel Industry
  Project leader : T.A. Wheat

Objective:

To determine the behaviour of refractories at high temperatures in contact with slags, and to report on specifications or modifications or alternative materials. This project also satisfies an expressed desire on the part of the steelmakers for an "independent" source of information beyond that of their suppliers, without necessarily implying lack of confidence in the suppliers, who are a continuing source of advice.

a) Two reports have been compiled: (1) behaviour of domomite refractories at high temperature in vacuum and (2) behaviour of magnesia/carbon refractories at high temperature in vacuum (four types of each evaluated against steelmaking slags).

The corrosion resistance of direct-bonded, tar-bonded, resin-bonded and carbon-containing dolomite in contact with slags showed that all have good corrosion resistance in contact with the basic slag. Most dolomite

exhibited excellent corrosion resistance to slag at below 1700°C. Above this temperature substantial slag in filtration occurred, resulting in rapid degradation of the brick. The slag corrosion retardation action of the graphite is readily apparent in the carbon-containing and resin-bonded dolomite.

The chemical-structural profiles of four types of MgO/C bricks with 15 to 24% carbon in contact with three different types of slag at temperatures of 1650 and 1700°C in vacuum were examined. Retardation of slag penetration owing to the presence of graphite was demonstrated. The corrosion resistance of the MgO is strongly dependent on the slag composition and increases with te basicity of the slag. In vacuum at 1700°C, extensive loss of components by vaporization was observed. This loss by vapourization/ sublimation was augmented by reduction of MgO in contact with graphite to Mg, which was deposited in the cooler parts of the furnace, thus opening up further surfaces to slag corrosion.

The corrosion resistance of fused cast chrome-magnesia block was examined. This material shows little volatilization in vacuum at high temperature, compared with both rebonded fused grain chrome-magnesia and MgO-C bricks. The slag resistance decreases with increasing temperature in this case.

Reports/Publications:

- D.H.H. Quon and K.E. Bell, "Corrosion resistance of doloma bricks in contact with slags from secondary steelmaking"; Division Report MSL 86-63 (IR).

- D.H.H. Quon and K.E. Bell, "Performance of magnesia-carbon bricks in vacuum at high temperature"; Division Report MSL 86-83 (IR).

- D.H.H. Quon and K.E. Bell, "Performance of magnesia-carbon bricks in vacuum at high temperature"; Division Report MSL 86-115 (OP&J).

- D.H.H. Quon and K.E. Bell, "Degradation of direct bonded chrome magnesia bricks in secondary steelmaking under vacuum"; Division Report MSL 85-105 (OP&J). (Accepted for publication in 1986 TMS-AIME Conference Proceedings).

Treatment - Industrial Minerals

- Project 30.37.01: Performance and Durability of Concrete Incorporating Supplementary Cementing Materials
  Project leader : V.M. Malhotra

Objective:

To develop data on mechanical and elastic properties and durability of

portland cement and portland cement concrete incorporating up to 65% less energy intensive materials, such as granulated blast furnace (B.F.) slag, fly ash, silica fume and limestone dust for applications in Canadian marine environments and in acidic waters of northern Canada; to develop a data base on portland cement concrete and portland cement/ B.F. slag/fly ash concretes for industrial applications involving exposure to sustained temperatures in the range 75-450°C for periods up to six months; to produce a low cost asbestos cement cooling tower fill resistant to corrosion in extreme environmental conditions such as freezing and thawing, soft and brackish waters, corrosive water and abrasion.

To conserve resources and energy it is imperative that less costly and less energy intensive materials be used in the production of portland cement and portland cement concrete. The most promising of the less energy intensive materials for replacing cement are granulated slag, fly ash and silica fume. The energy required to produce granulated slag is estimated at only 25% of that for portland cement, and fly ash and silica fume are industrial byproducts. As slag and fly ash from different sources have unique properties depending upon the raw materials used, it is essential that investigations be performed to obtain long term performance data on their use, with and without high-range water reducers, in concrete under Canadian climatic conditions.

Investigations were initiated on the development of superplasticizer, high-volume fly ashes in concrete. In these types of concrete, large volumes of cement are replaced by fly ash, and high dosages of superplasticizers are used to maintain a very low water-to-cementitious materials ratio.

Preliminary studies indicate that high-strength, high-modulus concrete can be produced employing the above approach. Research is planned to develop data using different types of cement and to monitor the long-term durability of such concretes.

Research continued under contract to develop an asbestos-cement cooling tower fill with improved durability. A two-level fractional factorial study was carried out to evaluate the effect of composition, fabrication and exposure mode on durability. In general, CSA Type 50 portland cement and slag cements outperformed CSA Type 10 and 20 cements in exposure to aggressive waters. The lowest flexural moduli are associated with the most isotropic products. The performance of a blast-furnace slag from a new source in Northern Ontario is being studied as a cement supplement in this application.

A comprehensive state-of-the-art report on use of fly ash in concrete was published as a special CANMET publication (SP 85-3).

The IRDC/CANMET project on fly ash was continued. The purpose of the project is the development of a data base for fly ashes from Argentina and Canada. Under the program, a second scientist from Argentina spent 4 months

at CANMET and a Canadian scientist visited Argentina for a period of two weeks.

Comprehensive investigations commenced to determine the freezing and thawing resistance of, and the effect of de-icing chemicals on, concrete incorporating supplementary cementing materials. A large number of concrete mixtures were made and test blocks were cast for testing. The data are still being processed but a preliminary evaluation indicates that concretes incorporating silica fume, slag and fly ash do show somewhat more scaling than the control concrete.

Investigations continued to develop data on the performance of granulated blast-furnace slags in concrete. The results reveal that the granulated slag from the pilot-plant installation at the Algoma Steel Works has satisfactory strength and durability characteristics, and is comparable with or superior to other Canadian slags, and can be successfully used to replace up to 50 percent cement in concrete. Several reports have been issued. A new plant using the Algoma slag has gone into production in northern Ontario to produce granulated slag; the next phase of the project will deal with the evaluation of the slag which is currently being produced at the plant.

Investigations were commended to determine the effect of high temperature concrete incorporating silica fume. The temperature range being investigated is from 150 to 450°C; the duration of temperature exposure is three days.

Several investigations dealing with alkali-aggregate reactions in concrete are in progress. In one investigation, the role of supplementary cementing materials to control the deleterious expansions in concrete due to the alkali silica/carbonate reactions is being investigated and a preliminary report has been published. The other investigations deal with the survey and evaluation of the rock types in New Brunswick and Newfoundland which may be potentially reactive.

Contracts:

- Reqn. 4-9236 MDA "Study of the alkali reactivity of potential concrete aggregates of New Brunswick", ADI Ltd. S.A. - J.A. Soles.

- Reqn. 4-9308 MDA "Development of engineering data on Nova Scotia fly ashes", L.E. Snow Ltd. S.A. - G.G. Carette.

- Reqn. 5-9185 MDA "State-of-the-art review of D-cracking of concrete", Hardy Associates Ltd. S.A. - E. Douglas.

- Reqn. 5-9250 MDA "Manitoba slag deposits, characterization, modifications, potential utilization", John Emery Geotechnical Engineering. S.A. - S.S.B. Wang.

- Reqn. 5-9255 MDA "Study of the alkali reactivity of potential concrete aggregates of Newfoundland", Golder Associates. S.A. - J.A. Soles.

- Reqn. 6-9157 MDA "Study of the alkali reactivity of potential concrete aggregates of Nova Scotia", Golder Associates. S.A. - J.A. Soles.

Reports/Publications:

- E.E. Berry and V.M. Malhotra "Fly ash in concrete"; CANMET SP 85-3, 1985.

- G.G. Carette and V.M. Malhotra "Performance of Canadian fly ashes in concrete"; CANMET 86-6; 1986.

- M. Cossette, E. Douglas, B. Nebesar and V.M. Malhotra "Development of asbestos-cement cooling tower fill with improved durability"; 1st Int. Conf. on Asbestos-Cement; 4-7 May 1986, Cannes, France.

- E. Douglas "Blast-furnace slag cement mortar and concrete - durability aspects"; Division Report MSL 86-123 (J). (To be published in Supplementary Cementing Materials).

- E. Douglas and R.T Hemmings "Characterization of granulated and pelletized blast-furnace slag and porosity and permeability of the slag/cement pastes"; Division Report MSL 86-28 (J).

- E. Douglas and R.T. Hemmings "Characterization of granulated blast-furnace slag for portland cement replacement in concrete"; Division Report MSL 86-67 (IR).

- E. Douglas, H.S. Wilson and V.M. Malhotra "Production and evaluation of a new source of granualated blast-furnace slag"; Division Report MSL 86-125 (J).

- E. Douglas and R. Zerbino "Characterization of granulated and pelletized blast-furnace slag"; Cement and Concrete Research, Vol. 16, pp. 662-670, 1986.

- C.D. Johnston and V.M. Malhotra "High strength lightweight concrete with up to 50 percent high calcium fly ash"; 1986, Division Report MSL 86-19 (J).

- V.M. Malhotra " Superplasticized low cement, high volume fly ash concrete for structural applications"; Division Report MSL 86-80 (J).

- V.M. Malhotra "Properties of fresh and hardened concrete incorporating ground granulated blast furnace slags"; Division Report MSL 86-136 (J).

- V.M. Malhotra "How to organize successfully an international conference"; Division Report MSL 86-141 (IR).

- V.M. Malhotra, K.E. Painter and A. Bilodeau "Mechanical properties and freezing and thawing resistance of high-strength concrete incorporating silica fume"; Division Report MSL 86-96 (OP&J).

- M. van Roode, E. Douglas and R.T. Hemmings "X-ray diffraction measurement of glass content in fly ashes and slags"; Division Report MSL 86-32 (J). (Accepted for publication in Cement and Concrete Research).

• **Project 30.37.02:** ERD - Concrete for Offshore Structures
Project leader : V.M. Malhotra

Objective:

To develop engineering data on high strength, low permeability, and high impact resistance concrete and grouts for offshore structures; to develop concrete permeability and ice abrasion resistance and NDT monitoring inspection tests.

Oil exploration and production activities in the off-shore arctic environment are expected to increase in the near future. It is anticipated that many of the offshore structures will be constructed of concrete. At present there are many unknown factors related to the performance of concrete structures in the arctic environment. The extreme cold adversely influences the properties of concrete. The ice creates additional problems of abrasion and impact. It is therefore essential that studies be performed to develop concretes which will be durable in the arctic environment. Such concrete should have high strength, low permeability and low unit weight. Also, testing methodology should be developed to determine abrasion resistance and permeability of these special concretes.

(a) The first phase of the development of high-strength lightweight concrete was completed and several reports were issued. The findings of the research were that air-entrained, high strength, lightweight concrete with a compressive strength approaching 70 MPa at 91 days and with densities of the order of 2000 kg/m^3, can be produced commercially using an expanded shale aggregate from Eastern Canada. These types of concretes can be made with or without the use of mineral admixtures. The second phase of the investigation will deal with developing concretes with strengths >70 MPa with local and or imported lightweight aggregates.

(b) The 8th yearly inspection of test prisms installed at Treat Island, Maine was performed. Visual checks were made and photographs taken. A display and a report was prepared and presented at the 2nd International Conference on the Use of Fly Ash, Silcia Fume, Slag and Natural Pozzolans in Concrete, held in April, 1986 in Madrid, Spain.

(c) Several papers based upon in-house contract research were presented at the Canadian Society of Civil Engineers/CANMET sponsored Two-Day International Workshop on Concrete for Offshore Structures which was held in St. John's, Newfoundland, September 1986. The development of a new ice abrasion and impact test, which was developed under a CANMET research contract was described. A press conference and a T.V. briefing session were held in 1986 to describe the development of the above test.

(d) A series of 12 high-strength concrete panels, 150 x 330 x 3660 mm in size, were installed on the side of an existing dock at Nanisivik in Baffin Island to determine the long-term effect of abrasion and impact on different types of concretes.

Contracts:

- Reqn. 4-9041 "Reproducibility of a new technique to measure the permeability of concrete", Laboratoire de Bréton Ltée. S.A. - G.G. Carette.

- Reqn. 4-9171 "Low-permeability high-strength fibre-reinforced normal weight concrete for offshore structures", Canada Cement Lafarge. S.A. - G.G. Carette.

- Reqn. 4-9173 "Development of a test to determine the resistance of concrete to abrasion and impact by ice under offshore arctic conditions", Arctec Canada Ltd. S.A. - V.M. Malhotra.

- Reqn. 4-9212 "Development of cementitious grouts for post-tensioned concrete members for use in offshore structures in the Arctic environment", B.H. Levelton and Assoc. Ltd. S.A. - H.S. Wilson.

- Reqn. 4-9246 "Evaluation of the suitability of existing repair materials to deal with potential types of damage", Ontario Hydro. S.A. - H.S. Wilson.

- Reqn. 4-9249 "Development of portable test equipment employing pulse-echo techniques to determine flaws in concrete", Techno Scientific Inc. S.A. - V.M. Malhotra.

- Reqn. 6-9003 "Performance of concrete panels exposed to ice-abrasion at Nanisivik, Baffin Island"; Louis A. Gottheil Eng., Montreal. S.A. - V.M. Malhotra.

Reports/Publications:

- V.M. Malhotra "CANMET investigations in the development of high strength lightweight concrete", Division Report MSL 87-33 (OP&J).

- V.M. Malhotra, G.G. Carette and T.W. Bremner "Durability of concrete containing supplementary cementing materials in marine environment"; Division Report MSL 86-130 (OP&J).

- T.J. Roots, A.M. Nawwar and V.M. Malhotra "Development of a test method to determine ice abrasion and impact resistance of concrete"; Division Report MSL 86-102 (OP&J).

- H.S. Wilson and V.M. Malhotra "Development of high strength lightweight concrete for structural applications"; Division Report MSL 87-11 (OP&J).

Biotechnology

- **Project 30.45.01: Bioleaching**
  Project leader : R.G.L. McCready

Objective:

To utilize microorganisms in extraction and beneficiation processes to exploit mineral deposits which cannot be treated ecomonically by normal processing.

(a) Bacterial leaching of sulphide ores

The objective is to develop an economically viable biohydrometallurgical process to extract and recover secondary metal values from sulphide ores, specifically those portions of mineral deposits which are left underground for mine support or which are below cut-off grade for conventional mining.

Typically 30% of mineral deposits are left untouched in most mining operations. Treatment of such residual resources by bacterial leaching would enable complete utilization of ore reserves.

Column leaching studies on Opemiska Copper Ore to compare bacterial leaching to bacterially-assisted leaching have been in progress for eight months. At present, the bacterially-assisted leach liquor (pH 1.5) contains 2.19 g Cu/L whereas the bacterial leach liquor (pH 2.3) contains 1.09 g Cu/L.

(b) Removal of silica from alumina ores (bauxite, clays, etc.) by biohydrometallurgical methods

The objective is to develop a biohydrometallurgical process to upgrade alumina ores by the solubilization and removal of silica. In the short term, the aim is to upgrade bauxite by reducing the level of silica which interferes with the production of aluminum by the Bayer Process.

About 30 microbial metabolites have been assessed for their ability to leach reactive silica from kaolinite. A metabolite has been found which is effective and it is currently being assessed using bauxites containing various concentrations of reactive silica.

(c) Heterotrophic leaching

The objective is to determine the effectiveness of heterotrophic leaching for the extraction of Ni, Co, and other base metals from low grade or refractory ores.

Some ores are not amenable to bacterial leaching by autotrophs or the recovery of the metal from a solution containing high concentrations of iron is difficult. If such ores could be leached economically under neutral or alkaline conditions, the metal of interest may be preferentially solubilized

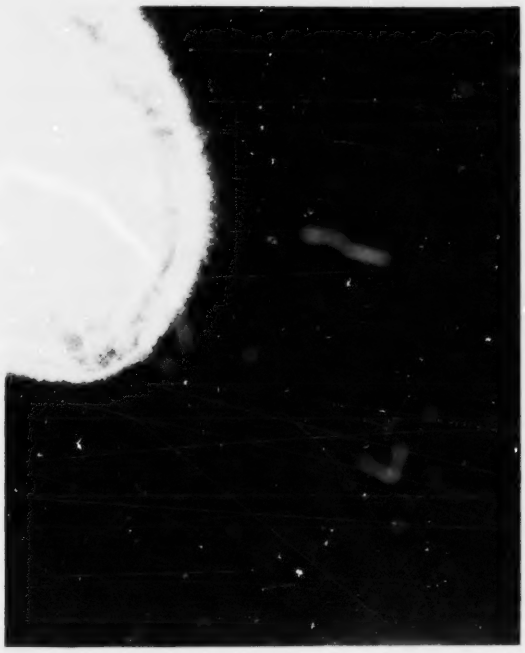

Fig. 3. Polar end of Thiobacillus ferrooxidans showing the polar flagella. Mag 170,000X

Fig. 4. The pitting resulting from the microbial oxidation of sphalerite. Mag 20,000X

without iron solubilzation occurring, thereby making recovery of the metal from solution much easier.

About 30 microbial metabolites have been assessed for their ability to preferentially leach Ni from pentlandite. One group of metabolites is very effective in solubilizing Ni and Cobalt without solubilizing iron at an alkaline pH. Studies are continuting to assess the effects of metabolite concentration, pH, temperature and leaching with combinations of two or more metabolites.

Contracts:

- Reqn. 6-9126 "Determination of activity parameters in Thiobacillus ferrooxidans strains as criteria for mineral leaching efficiency", Dept. of Microbiology, University of Manitoba. S.A. - R.G.L. McCready.
- Reqn. 6-9159 "Development of thermophilic biohydrometallurgy to enhance precious metal extraction", Coastech Research Inc. S.A. - R.G.L. McCready.
- Reqn. 6-9197 "Research study to determine the source of oxygen during bacterial oxidation of mineral sulphides", Department of Physics, The University of Calgary. S.A. - R.G.L. McCready.
- IRAP Project CA-910-786-A "Underground biological in-place leaching of uranium ore - Phase II", Denison Mines Ltd. S.A. - R.G.L. McCready.

• **Project 30.45.02:** Biological Impact on Unit Operations
Project leader : R.G.L. McCready

Objective:

To identify, quantify and apply biological phenomena which enhance performance of unit operations used in the Mineral Processing and Mineral Resource Extraction Industries.

Projects in this area include the bioadsorption of metals from process solutions or effluents, the microbial degradation of organics which interfere with mineral recovery from ores or concentrates, the microbial recovery of metals from mill effluents and biological mitigation of acid mine drainage.

The various projects were supported by contract funds from the National Biotechnology Strategy.

Contracts:

- Reqn. 5-9156 "Microbial control of tailings dump leaching", Department of Biology, The University of Ottawa. S.A. - W.D. Gould.

- Reqn. 6-9052 "Optimization of fungal adsorption of uranium and cell immobilization and pelletization", Acres, Davy McKee, Engineering Inc. S.A. - R.G.L. McCready.

- Reqn. 6-9103 "Microbial degradation/alteration of carbonaceous species in Canadian ores and concentrates, Phase II", Witteck Development Inc. S.A. - R.G.L. McCready.

- Reqn. 6-9118 "Growth dynamics of naturally colonizing characeae in abandoned tailings ponds", Boojum Research Ltd. S.A. - R.G.L. McCready.

- Reqn. 6-9164 "Use of biomass to recover uranium from bioleach solutions", McMaster University. S.A. - R.G.L. McCready.

- IRAP Project L2730-1064 "Biorecovery of selenium", CMS Rotodisk. S.A. - R.G.L. McCready.

- IRAP Project CA910-6-1078 - Chara Process "Biological polishing of alkaline effluents", Boojum Research Ltd. S.A. - R.G.L. McCready.

• **Project 30.45.03:** Biotechnology Networking
Project leader : R.G.L. McCready

Objective:

On a continuing basis to maintain and expand a network to improve the interaction and communication between the research community and Canadian Industry, and to improve the availability and accessibility of relevant information.

Personnel from MSL:

1. Prepared and published four BIOMINET (Mineral Leaching and Metal Recovery Network) Newsletters to keep members aware of current research projects and developments in the application of biotechnology in the mineral industry.

2. Organized, prepared and presented a two-day workshop on "Basic Microbiology for the Mineral Industry" on November 6 & 7 which was attended by 39 participants. CANMET SP 86-7.

3. Participated in a Symposium on "Biotechnology in the Mineral Industry" as part of the Canadian Society of Microbiologists' Annual Meeting in Toronto. MSL 86-69 (OP).

4. Published the BIOMINET Proceedings from the 1985 Annual Meeting. CANMET SP 86-6.

5. Organized and participated in the Annual BIOMINET Meeting which was attended by 42 members at the Howard Johnson Hotel in Oakville, Ontario.

6. Participated in the Biotechnology Session of the CIM Annual Meeting in Toronto. MSL 86-105 (OP).

7. Participated in the workshop on "Metal Recovery from Solutions Using Natural Products". Lancaster, England. MSL 86-45 (OP&J).

8. Participated in the workshop on Biotechnology Applied to Mining and the Mineral Industry", Idaho Falls, Idaho.

9. Participated in a biotechnology day at the ALCAN Arvida Research Centre.

10. Published two biotechnology articles in the Summer issue of GEOS.

BIOMINET database:

New organizations were added to the BIOMINET database as survey responses continued to arrive. Many address changes and deletions were required; mailing labels are produced as required.

Extraction - Metallic

- **Project 30.52.02:** Chloride Processes for Sulphide Ore Treatment
  Project leader : D.H. Bell

Objective:

To develop and evaluate viable chloride metallurgical processes which will achieve the goals of metal recoveries above 90% and the elimination of SO_2 emissions by yielding elemental sulphur or stable sulphides from bulk sulphide concentrates.

Although, New Brunswick has the largest reserves of zinc, lead and silver in Canada, the complexity of these sulphide orebodies has resulted in inefficient recovery of high-value saleable products using existing technology. In order to improve metal extraction efficiency, it is necessary to produce a bulk concentrate. However, because of its complexity and its relatively low grade, this bulk concentrate is not amenable to treatment by conventional processing technology. CANMET has been investigating and evaluating chloride processes for the treatment of these complex concentrates. Work at CANMET and under contract has largely confirmed the basic flowsheet for a ferric chloride leach process. Current activities relate mainly to a complete technical and economic assessment, and demonstration of process alternatives for New Brunswick and similar other complex sulphide concentrates. The processes under study are expected to lead to significant cost reductions and higher metal recoveries.

Increasing concern over "acid rain" will likely result in the enforcement of alternative long term solutions desirable. Processes which yield elemental sulphur instead of SO_2 are potentially viable alternatives. Chloride technology offers such a process, however, before industrial acceptance can be gained, it must be well demonstrated on both technical and economic bases.

(a) The ferric chloride leach (FCL) process

The FCL process has been developed, both within CANMET and by contract research, into a technically viable process which meets the objective of 90% recovery and elimination of SO_2 emissions. The process appears to be economically competitive with the Sheritt-PSA process (now commercial) and may out-perform the RPC-SRL process (now under pilot development). Process development work at CANMET during the 1986/87 year has resulted in the revised flowsheet shown in Figure 5. Improvements have been made in

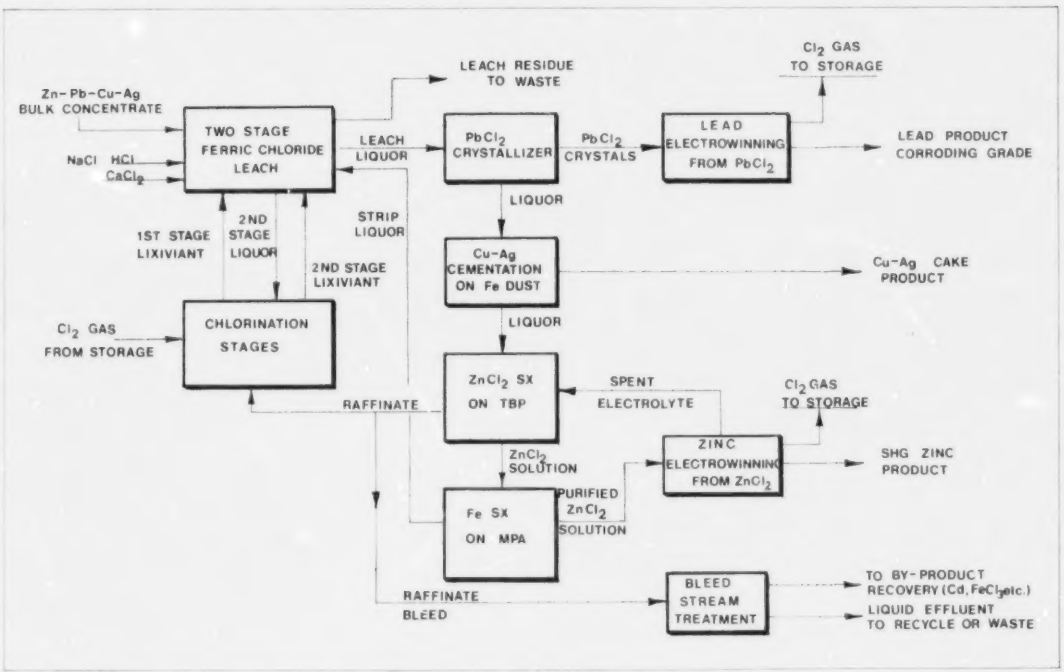

Fig. 5. The CANMET ferric chloride leach process

(i) Leaching: FCL process development

A two-stage leach of the pyretic bulk concentrate under low-acid conditions (0.1 to 0.2 M HCl) resulted in extractions for Pb, Zn, Cu and Ag of 99.7%, 99.3%, 97.4% and 95.8% respectively. Acid consumption decreased to 25 g of HCl per kg of concentrate, from 49 g/kg in the previous testwork.

leaching, cementation, crystallization and solvent extraction of zinc chloride; in addition new SX technology has been developed for the removal of impurities (Fe(III), Cd, Bi, Pb, Cu) from zinc chloride electrolyte feed solution. These improvements have been effective in achieving capital and operating cost reductions relative to the previous flowsheet, and promise enhanced economic performance of the process.

(ii) $PbCl_2$ recovery and cementation of Cu and Ag

The low-acid leach liquor was cooled to precipitate $PbCl_2$ crystals, and subsequently treated with Fe dust to cement Cu and Ag. The resulting solution was stable, in that cemented copper did not redissolve and iron hydrolysis did not occur; the solution after cementation met the process specifications for copper and silver of 1 mg/L each and pH of about 1. The $PbCl_2$ product quality was similar to that of previous testwork.

(iii) Zinc chloride solution purification

Previous testwork had established that tri-butyl phosphate (TBP) will efficiently extract zinc chloride from the leach liquor. Co-extraction of 1 to 2 g/L of Fe(III) and some lead and copper was a problem however. Further studies have identified a solvent extraction method for removing iron (III) and other impurities from the $ZnCl_2$ solution. The raffinate is electrolyte-quality $ZnCl_2$ solution with Fe(III) content < 50 ppm, and the strip liquor can be recycled to the leach circuit. Work continues towards continuous testing of this purification sub-circuit.

Some testwork was also carried out to identify a suitable extractant for copper from the leach liquor should it prove desirable to recover copper metal rather than the current cement-copper product.

(b) Leaching of metals and sulphide minerals

(i) Silver minerals

Fundamental kinetic studies have been carried out on the ferric chloride leaching of AgCl and Ag_2S. Relatively rapid rates were observed in all instances; the rate increased with increasing temperatures or increasing chloride concentrations of the leaching medium. The rate was insensitive to the Fe(III) concentration and the pH, but decreased with increasing AgCl (reaction product) concentrations in solution. The experimental results indicate parabolic rate kinetics with aqueous diffusion control. A report has been prepared on this work.

A rotation disc study of silver dissolution in ferric ion media was completed and a report prepared. The variables studied were temperature, ferric ion, ferrous ion, acid concentrations, disc rpm and sodium sulphate concentration.

(ii) Zinc electrowinning from aqueous chloride electrolyte

Smooth, compact, dendrite-free zinc deposits were electrowon from acid zinc chloride electrolyte in a diaphram cell, at both the bench and semi-pilot level. Full-height cells were used in support of the FCL process simulated pilot-plant studies. The zinc cathode analysed > 99.989% Zn.

(iii) Copper electrowinning from aqueous chloride electrolyte

Testwork has been completed to determine design parameters for a diaphram cell to electrowin high-purity copper crystals from aqueous chloride electrolyte.

(iv) Lead electrowinning from aqueous chloride electrolyte

Conditions were established to electrowin loose, uniform lead crystals, free of NaCl and $PbCl_2$ salts, from an aqueous chloride electrolyte. A report has been issued.

(v) Fundamental studies on silver cementation on copper and lead

The kinetics of silver cementation onto copper and lead from a 3.0 M NaCl and 0.3 M HCl solution, using a rotating disc technique, have been studied. The effects of temperature, disc rotation speed and solution volume were investigated and correlated to change in the deposit morphology. A paper has been prepared and accepted for publication.

(vi) Silver and copper cementation on granular iron

The use of granular iron to cement Ag and Cu from simulated FCL leach liquor was studied, in support of the FCL process. The results indicate that iron is technically and economically superior to lead as a cementing agent. The results have been reported.

(vii) Solubility of $PbCl_2$

The solubility of lead chloride in more concentrated iron chloride media, of direct interest to CANMET's FCL process, has been studied. The influence of ferric and ferrous ions is being examined, using available data for stability constants, activity co-efficients and solution models.

(viii) Purification and regeneration of leach solutions

Studies of the chlorination of FCL process leach solutions were completed. The effect of temperature, pressure, reagent concentrations and stoichiometry on the overall mass transfer rate was determined. Reliable pyritic measurements were made possible by improvements in reactor design and process control. The results were useful for process optimization and for scale-up purposes.

Contracts:

- Reqn. 5-9174 "Lead chloride electrolysis: New technology appraisal and conceptual design of a cell", SNC Inc. S.A. - J.E. Dutrizac.

Reports:

- P.L. Bedard, P. Richer and K.G. Tan, "Interfacing of the Pye Unicam PU8610 UV/VIS spectrophotometer with the Osborne 01 microcomputer"; Division Report MSL 86-170 (TR).

- J. Dutrizac, "The kinetics of floride chloride leaching of silver and antimony silver and silver chloride"; Division Report MSL 86-43 (J).

- J. Dutrizac, "Leach of silver chloride and alumina silver in ferric chloride media"; Division Report MSL 86-49 (J).

- D.J. MacKinnon and J.M. Brannen, "Lead electrowinning from aqueous chloride electrolyte"; Division Report MSL 86-42 (TR).

- D.J. MacKinnon and J.M. Brannen, "Cementation of copper and silver on granular iron from simulated iron chloride leach solutions"; Division Report MSL 86-107 (TR).

- K.G. Tan, K. Bartel and P.L. Bedard, "Lead chloride solubility and density for chloride leach process - Part 1 - Lead chloride in binary aqueous solutions"; Division Report MSL 86-41 (J).

- K.G. Tan and P.L. Bedard, "Development of a mini plant chlorinator for ferric chloride leach processes"; Division Report MSL 86-98 (OP&J).

• **Project 30.52.03:** Gold
Project leader : G. Pouskouleli

Objective:

To improve existing or develop new, environmentally acceptable processes to increase the recovery and reduce the cost in the extraction of gold and associated precious metals, with special emphasis on refractory ores, e.g.., arsenical, etc.

Two important aspects for the Canadian gold industry are the ores which are low grade, refractory and difficult to treat and concerns about the environmental impact caused by existing mining and milling technologies. The existing orebodies are low grade and being refractory mainly in arsenopyrites need special pretreatment so gold can be liberated and leached. The existing technology for this pretreatment is the roasting with the known emissions of arsenic oxides while leaching with CN^- still has the

experts worried about a possible impact on the environment. Thus, CANMET has an important role in developing a more economical ore treatment processes which will cause minimum damage to the environment.

(a) Mineralogical identification of refractory and complex ores

Mineralogical work is ongoing to produce a data base on the characteristics of Canadian refractory gold ores. Twelve Canadian ores have been identified which will be considered typical refractory gold ores, based on a review of domestic resource data. These ores will be the focus of mineralogical characterization of such ores in the coming year.

(b) Mineral processing

(i) Offshore placers

Sampling methodologies and processing requirements for evaluating placer gold deposits located off the Nova Scotia coastline were investigated. Preliminary results indicate that bottom mounted vibra core drills operated from small vessels and on-board centrifugal separators to concentrate the fine grained heavy minerals are required. Larger size samples are being collected for CANMET to determine processing requirements.

(ii) Recovery from auriferous deposits

Samples of ores and tailings have been processed by sorting, grinding, gravity, flotation, cyanidation to determine flowline requirements from several Nova Scotia locations, while the leachability of the massive low grade White Channel placer gravels was investigated. Figure 6 shows a Knelson centrifugal separator manufactured in Canada, and used at CANMET for the recovery of fine gold.

(iii) Placer gold operations in the Yukon

Studies were undertaken to reduce costs, increase recoveries and improve effluent water quality in placer gold operations. The programs included pumping of sluice tailings, cycloning of tailings for water impoundment, use of flocculants, testing of sluices and jigs, research towards optimizing sluice operations, and a study of current and alternative materials handling methods.

(iv) Electronic sorting

Testwork by Aggen Inc. of Peterborough, Ontario is continuing on electronic sorting of gold ores. Aggen Inc. has built a portable production scale unit capable of sorting by photometric and conductivity principles and plans in 1987 to commence contract sorting work in the Beardmore Area Northern Ontario. A CANMET representative was assigned, following the request of the Ontario Ministry of Natural Resources, to act as technical adviser for this testwork program.

(iv) Royal Mint sweeps

Under contract to the Royal Mint, CANMET designed a flowline recovering 90% of the gold as a 50% gold concentrate by dry separation from high-grade sweeps, crucibles and furnace slags and bricks.

(c) Pretreatment of refractory concentrates

(i) Alkaline or acidic pretreatment under O_2 pressure

A flotation concentrate having approximately 9.0 oz/tonne was oxidized under acidic or alkaline conditions under O_2- pressure (2000 KPc-O_2 pressure, 185°C to 195°C, 2.5 - 3-5 h, 40% solids). Solids obtained after this pretreatment were subjected to alkaline cyanidation which yielded 96-98% extraction.

(ii) Microwave pretreatment

Microwaves were applied in the calcination of this concentrate. More than 80% of As and S were removed by irradiating 1000.0 g of the concentrate with 6 kw power for 12-14 minutes. Alkaline cyanidation of this calcine resulted on 98% gold and 62% silver extraction.

(d) Leaching

(i) Heap leaching in the Yukon

The feasibility of heap leaching gold from a low grade oxidized deposit was studied and results have shown that the ore responds well to leaching, and despite the northern latitude, the climate would support 200 leaching days per annum. A program for a 10,000 tonne test leach is considered for 1987.

ii) Thiourea leaching

Acidic thiourea leaching of gold ores and concentrates and a chalcopyrite concentrate as an alternative to alkaline cyanidation was conducted. Leach tests were also conducted on the pretreated concentrates. Test data indicated that acidic thiourea solubilized gold at a faster rate than the alkaline cyanide, but like alkaline cyanide, acidic thiourea was not effective for gold leaching from arsenopyritic, refractory gold ores or concentrates. Different ways in order to minimize thiourea consumption were examined while purification studies on the leach solution and synthetic thiourea solutions continue. Gaseous reduction of gold from the Au(I) thiourea complex is a promising alternative to cementation with a metallic powder or electrolysis. High recoveries were obtained (99% Au) without any thiourea decomposition.

(iii) Other lixiviants

Evaluation of other lixiviant systems is ongoing. A new product (Bio-D) was examined. Preliminary tests found process costs to be high. Other halide systems are under evaluation.

(iv) Solvent-in-leach

The concept of solvent-in-leach has been given a preliminary examination. The presence of an organic extractant enhances the leaching kinetics for gold while increased temperature shows further enhancement of kinetics.

(e) Solution treatment

(i) Ion exchange vs carbon sorption

The recovery of gold by single-stage, deep-fluidized bed, ion exchange in comparison with sorption on carbon was examined. Bench tests were conducted to compare ion exchange resins with carbon for the recovery of gold from cyanide solutions. These data will be used to set up a continuous ion exchange column. Amongst the carbons tested, Calgon PCB, Calgon GRC 22, Norit 2515 and Haycarb XT4 exhibited superior leading efficiencies. Based on overall performance, Calgon GRC 22 was selected for the subsequent testing in the single-stage deep-fluidized bed contractor. Of the resins evaluated, the strong base IRA 400 and weak base Duolite A-7 resins will be considered for the continuous testing. Sorption is enhanced at increased temperatures in direct contrast to use of activated carbons. However, excess cyanide adversely affects gold loading onto resins. Although weak base resins show poorer loading characteristics than strong base resins, elution is much simpler and more complete and can be accomplished with dilute caustic.

(ii) Resin-in-pulp

Evaluation of resin-in-pulp technology was performed after a comprehensive literature survey, discussions with resin manufacturers in order to obtain resins for bench testing and in a mini-plant campaign for flowsheet optimization. Of seven resins investigated, a weak base, high pKa macroporous experimental resin by Dow Chemical proved the most promising. Good selectivity of gold over most of the common base metals was achieved, and gold loadings reached 17.8 kg Au/t of resin when extracted from a 45% solids cyanidation leach slurry containing 3.5 ppm Au and 0.77 ppm Zn. SEM examination of the resin showed a small amount of surface attrition. A pilot plant operation will be run in 1987/88 to determine the technical and economic viability.

(iii) Solvent-in-pulp

Long-chain quaternary ammonium salts appear promising for use in solvent-in-pulp systems. Gentle agitation of the system. without dispersion

of one phase in the other, has been found to give good gold recoveries and reasonable kinetics. A small pilot plant is anticipated in the next year.

(iv) Direct reduction from solution

Direct reduction for the purification of gold and PGM metals was studied as a part item of the new concept of "bulk extraction - selective stripping" of these metals. Direct reduction systems for the selective precipitation of gold, platinum and palladium from organic as well as from aqueous phases were studied. The chemical behaviour and response of these metals to the reduction systems were examined and parameters for specific powder production were established. As a result of these studies an easy method, relatively cheaper in energy requirements, was found for production of high purity gold crystals from contaminated solutions as seen in Figure 6.

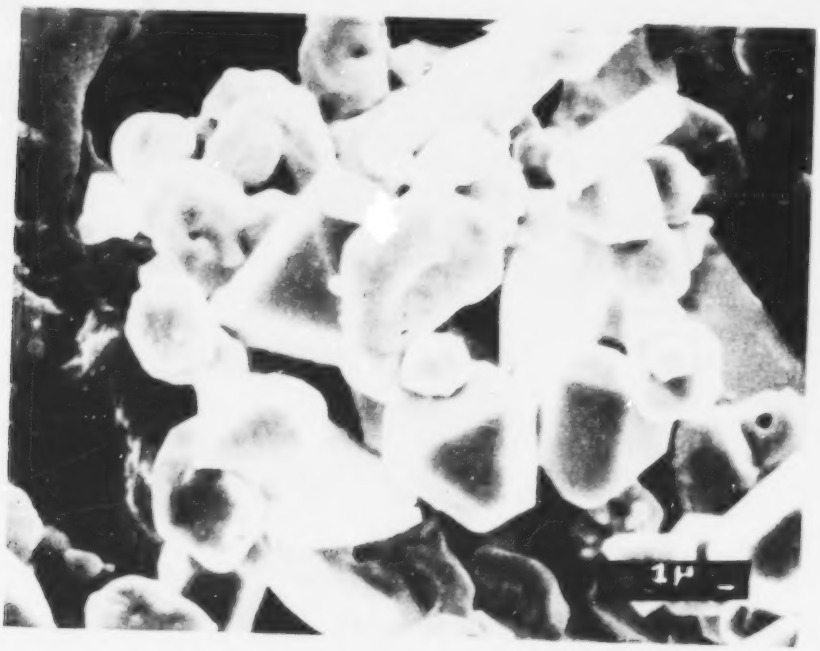

Fig. 6. High purity gold crystals

(f) Platinum/Palladium

A system for the separation of platinum and palladium was studied to support the CANMET's patent on "bulk extraction - selective stripping" of gold and PGM metals. The separation and recovery of Pt/Pd from leach solutions was studied. Using a solvent extraction system based on an 8-hydroquinoline alkylated derivative bulk extraction of Pt and Pd from chloride solutions takes place with very fast kinetics and high distribution ratios. The

stripping of the loaded organic can be achieved with H_2O which strips Pt and with strong HCl which strips Pd. Other stripping systems can be used if a high purity mixture of Pd/Pt is required. The influence of other metallic values in the feed solution, e.g., Se, Te, Bi, etc. was studied as well as temperature, diluents, modifiers. These studies enabled us to suggest different flowsheets for the recovery and separation of PGM metals.

(g) Analytical development

Methods have been developed for the determination of free thiourea, complexed thiourea and formamidine disulphide in leach solutions from gold-bearing ores.

Contracts:

- Reqn. 5-9224 "Ion implantation of sulphides", A.E.C.L. Chalk River Nuclear Labs. S.A. - L.J.P. Cabri.

- Reqn. 5-9230 MDA "Evaluation of equipment and processes to sample offshore placer deposits from small fishing vessels", Noranda Ltd. S.A. - D.M. Doyle.

- Reqn. 5-9265 MDA "Recovery of gold from auriferous sulphide ores and concentrates", Lakefield Research. S.A. - D.M. Doyle.

- Reqn. 6-9006 "Heap leaching in the Yukon - A metallurgical and engineering assessment, UP-W-264", Witteck Development Inc. S.A. D.M. Doyle.

- Reqn. 6-9053 "Evaluation of resin-in-pulp technology for Canadian gold ores - Phase II", Witteck Development Inc. S.A. - G.M. Ritcey.

- Reqn. 6-9054 "Recovery of gold by single-stage deep-fluidized bed, ion exchange and carbon technologies - Phase II", Ontario Research Foundation. S.A. - G.M. Ritcey.

- Reqn. 6-9055 "Development of reductive precipitation process for production of high purity gold, platinum and palladium", McGill University. S.A. - G. Pouskouleli.

Reports/Publications:

- G.P. Demopoulos, G. Pouskouleli and G.M. Ritcey, "A novel solvent extraction system for the refining of precious metals"; ISEC '86 Proceedings; 1986.

- G. Deschênes, P.J. Prud'homme and E.W. Wong, "Recovery of gold from thiourea solutioons: Investigation of cementation with metal powder, activated carbon, ion exchangers and solvent extraction - Progress report"; Division Report MSL 86-26 (TR).

- G. Pouskouleli, S. Kelebek and G.P. Demopoulos, "Recovery and separation of platinum and palladium by co-extrction and differential stripping"; Division Report MSL 86-164 (OP&J).

• Project 30.52.04: Plasma Reactors
Project leader : J.M. Skeaff

Objective:

To investigate and develop applications of plasma technology in the fields of energy utilization and pyrometallurgy as a means of increasing energy use efficiencies and of substituting electricity for fossil fuel.

Plasma technology has the potential in many instances for the efficient substitution of electrical energy for fossil fuels utilization as well as for completely new applications. It is also evident that plasma technology has developed to the state where applications on an industrial scale are being seriously considered, are planned or are a reality. However, Canada, although possessing more than adequate supplies of relatively inexpensive electricity, lags behind the development of industrial plasma technology. To assist in the development of these applications, CANMET has accepted the lead agency role in the field within the Federal Government.

(a) Plasma technology in metallurgy

Several shakedown trials have been conducted on a 100 kVA plasma reactor. The causes of initial problems in achieving a steady-state arc and the desired operating temperature were identified as being the transformer output voltage and insufficient argon purging time of the reactor. This type of plasma appeared to be sensitive to the total energy balance of the system, since arc stability was observed to improve significantly at thermal steady state. The optimum voltage level for the unit has now been determined as 45 volts at each electrode, at which level a stable extended arc was achieved on a continuous basis and the operating temperature of ~1650°C was attained in less than 30 minutes. Initial tests with small amounts of a feed of hematite, coke and lime were successful and will lead to operation at 30 kg capacity.

Meetings and discussions were held on plasma technology and its applications, particularly in metallurgy. Technical advice has been provided on a contract on plasma applications conducted at Ontario Hydro on behalf of the Canadian Electrical Association. Studies and proposals related to plasma production of ferrovanadium from Athabasca oil sands fly-ash, synthesis of ultra-fine silicon carbide, production of titanium silicide and iron-titanium silicides, petroleum coke gasification and a survey of the potential of plasma technology applications in Canada have been reviewed.

Contracts:

- Reqn. 6-9189 "Investigation into the feasibility of direct reduction and smelting of sulphide ores in an LB furnace", W.K. Lu, McMaster University, Hamilton. S.A. - J.M. Skeaff.

- Reqn. 5-0870 "D.C. plasma arc furnace", R. Stratten-Crawley, INCO Ltd., Toronto. S.A. - J.M. Skeaff.

- **Project 30.52.05: Impurities in Copper Refining**
  Project leader : J.E. Dutrizac

Objective:

In co-operation with the Canadian copper industry, to develop, by 1990, improved technologies for the characterization, deposition, control and processing of impurities in electrolytic copper refining.

Canada is a major producer of primary copper, and all the nation's primary copper is produced by smelting. During smelting, many of the impurities contained in the copper concentrates are collected in the blister copper smelter product. It is necessary to remove such impurity elements from the blister copper both to meet market requirements for copper conductivity and to recuperate valuable byproducts. Electrorefining in a $CuSO_4$-H_2SO_4 electrolyte is universally used for this purification. The issue of impurity control is of concern to all producers as it impacts directly on tankhouse operation and the profitability of the entire plant. Most of the Ag, Au, Se and Te form insoluble products (anode slimes) during electrorefining. Although anode slimes have been processed for over a century, much remains unknown about this process, and the problems associated with anode slimes are expected to intensify. If the Canadian smelting industry is to remain viable in the face of low copper prices and keen international competition, technological responses must be developed to overcome current problems.

(a) Characterization of copper anodes and anode slimes

Mineralogical studies have been done on the copper anodes from all four Canadian copper producers. Silver occurs mostly in solid solution in the metal; gold occurs both in solid solution in the copper and as Cu-Ag-Au-selenide inclusions. To determine the distribution of Au and Ag more precisely, proton probe microanalyses are planned, and trace element standards have been prepared for these studies. Although most of the tellurium is in solid solution in the selenides, Pb, As, Sb and Bi occur as oxide inclusions closely associated with the selenides. The anode slimes made in the Kidd Creek, CCR and INCO refineries also have been characterized, and the reactions occurring during electrorefining have been elucidated. Silver dissolves and reacts with Cu_2Se to form Ag-rich

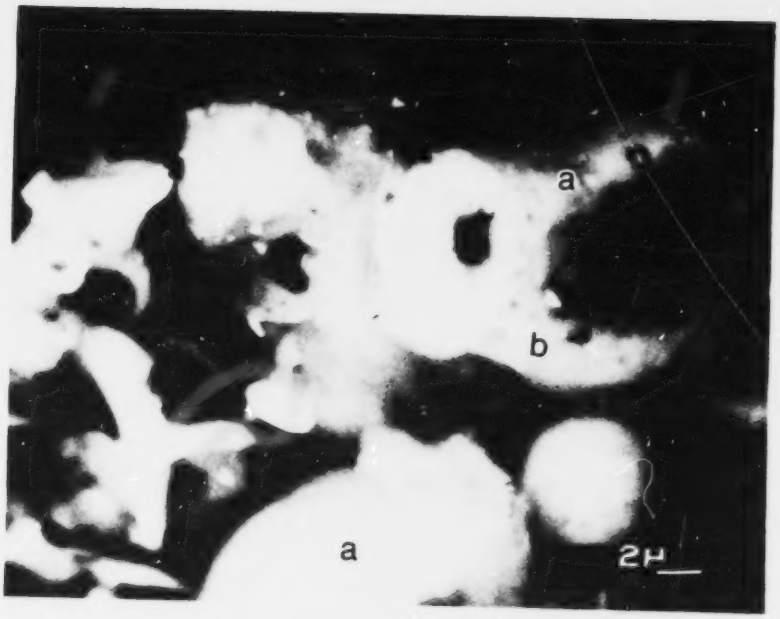

Fig. 7. Several Cu-Ag selenide particles (a) present in a commercial anode slime; several tiny grains of gold metal (sharp, white grains (b)) adhere to the surface of the selenides.

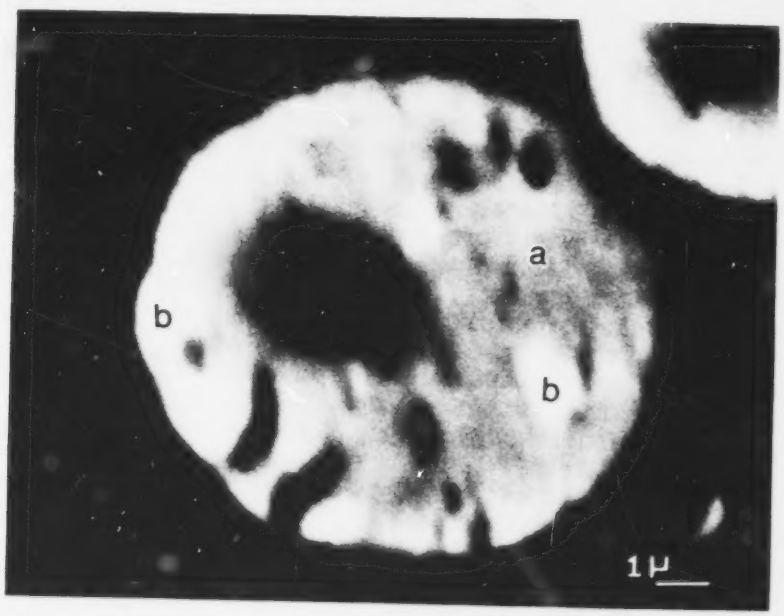

Fig. 8. A complex Cu-Ag selenide particle (a) in a commercial anode slime. The white areas (b) indicate high concentrations (to 12% Au) of dissolved gold.

selenides in the slimes layer; some metallic silver also occurs. Most of the gold reports as < 1 μm metal particles (Fig. 7), but some remains in solid solution in the selenides (Fig. 8). Copper selenides present in the anodes pass directly into the slimes layer, and determine greatly the morphology of the slimes. The Pb, As, Sb and Bi oxide inclusions are rapidly attacked; Pb and Bi remain as sulphates in the slimes layer, but As and Sb dissolve. Subsequently, some of the arsenic seems to be re-precipitated, likely as copper arsenate. The role of copper sulphate in anode passivation has been clarified.

(b) Anode passivation

Anode passivation effects are of major industrial concern. At CANMET, several foreign language papers on anode passivation were translated, and the translations were distributed to the industry; also, CANMET support was given to a cooperative research proposal to study anode passivation at Laval University. The role of oxygen, silver and selenium on anode passivation and on slimes formation and cathode quality is being studied; suitably doped anodes are being prepared under contract, and experimental work will begin shortly.

Local saturation of the refining electrolyte with $CuSO_4$ causes anode passivation. Available $CuSO_4$ solubility and density data appear to be outdated or subject to analytical errors. A new technique was developed, therefore, to measure both the density and $CuSO_4$ solubilities, and this technique currently is being used to determine the relevant systems.

(c) Arsenic in copper refining

The presence of arsenic in copper anodes can reduce anode passivation and improve cathode quality by retaining more of the slimes on the anode. Efforts are underway to electrowin a copper arsenide product suitable for doping anode copper. A literature survey on this topic has been completed, and a draft report has been prepared. Experimental studies using copper electrolyte with ~10 g/L Cu^{2+} and 1-4 g/L As^{3+} (as As_2O_3) consistently yield copper arsenide products, and the amount of arsenic co-deposited increases with increasing arsenic concentration and current density. The effect of the As/Cu ratio on the reaction as well as the co-evolution of arsine gas currently are being studied.

(d) Alternate technologies

Total chemical dissolution of anode slimes offers potential advantages over conventional processing technologies. Testwork on such an approach was completed on Kidd Creek anode slimes which are characterized by high levels of Ag, Pb and Se. Comparative testwork showed that ammoniacal pressure leaching offers significant advantages over other hydrometallurgical options; in particular, the ammoniacal leaching route gave reduced retention times and higher Cu and Se extractions. An assessment of the patentability of this option is underway.

Contracts:

- Reqn. 5-9109 "Development of an improved method for monitoring the composition of electrolyte in the copper refinery", INCO Ltd. S.A. - D.J. MacKinnon.

Reports/Presentations:

- T.T. Chen and J.E. Dutrizac, "Mineralogical characterization of anode slimes from the Kidd Creek copper refinery"; Division Report MSL 86-103 (J).

- T.T. Chen and J.E. Dutrizac, "A mineralogical study of anode copper and copper refinery anode slimes"; 25th Annual Conference of Metallurgists, Toronto, Ontario, August 1986.

- T.T. Chen and J.E. Dutrizac, "Mineralogy of anode copper and copper anode slimes from the Kidd Creek copper refinery", Joint CANMET-Industry-University Research Project Meeting, Timmins, Ontario, June 1986.

Extraction - Radioactive

- **Project 30.61.01:** Uranium Process Development
  Project leader : G.M. Ritcey

Objective:

To effect significant improvements in uranium processes with respect to recovery of by products, process efficiency, economics and environment impact.

Canadian uranium is a well-established and prosperous industry. However, as new ores are discovered and as environmental concerns increase, the limitations of the well known conventional sulphuric acid leaching process become more evident. At CANMET, a systematic review of the existing process has identified many areas for new technology using chloride metallurgy. Interestingly, benefits may be converging into an entirely new flowsheet incorporating the strong points of both approaches. The benefits could well play a significant role in future uranium plants.

(a) Research activities on the uranium project, as in previous years, were directed towards the development of a leaching process for high extractions of U, Ni, As and Ra from a high-grade uranium ore from Northern Saskatchewan. Three approaches were undertaken: (i) radium preleaching followed by HCl leaching of U, Ni, As and the residual Ra; (ii) HCl leaching only on the uranium ore; and (iii) counter-current acid leaching.

i) All these investigations were conducted on Midwest Lake uranium ores.

Midwest Lake uranium ground to 50% -0.007 cm size was first treated with a 2 M KCl solution at 50°C, 25% solids, 2 hours. Approximately 60% of radium was removed. This radium preleached uranium ore was treated with HCl (88.0 kg/t), 70°C, 4 h, 50% solids, O_2 as an oxidant and yielded U 99.5%, Ra 98%, Ni 88% and As 90% extractions respectively; the final leach residue contained 108 pCi/g solids radium.

ii) The HCl leaching only on the Midwest Lake uranium ore provided high extractions for U, Ni, As, but radium extraction was only 93%; the leach residue contained 381 pCi/g solids radium.

iii) Counter-current acid (HCl or H_2SO_4) leachings were conducted on Midwest Lake uranium ore as well as on an Elliot Lake uranium ore. Test results indicated that 4-stage counter-current H_2SO_4 leaching of an Elliot Lake uranium ore provided high extractions not only for U (97%) and Th (86%) but also for radium (40%) when O_2 (g) was utilized as an oxidant, the leach residue still contained 180-190 pCi/g radium. Furthermore, 4-stage HCl counter-current leaching of Midwest Lake U-ore provided overall extractions of U 99.5%, Ni 80%, As 81% and Ra 96% respectively. However, the leach residue still contained 226 pCi/g solids radium.

(b) Radium adsorption

Barite mineral, of fine particle size (0.003 cm) represents a potentially efficient adsorbent for the radium present in uranium tailings pond overflow. Columnar operation utilizing fine particulate material proved inoperable, particularly downflow. Upflow operation resulted in channelling or short-circuiting, depending upon flowrates employed.

A mechanically-stirred reactor was utilized, which contained a slurry at 5% solids (Barite). The feed solution, lysimeter effluent analyzing approximately 100 pCi ^{226}Ra per litre, was pumped through the unit at a flowrate which resulted in a retention time in the slurry of 5.5 hours.

Throughput to date, on continuous operation, is 65 L per gram of barite for a total quantity of solution treated equaling 3.2 tonnes. At this point in time the adsorption efficiency is about 85% of the input radium. The estimated loading is > 5000 pCi per gram of barite.

For the initial 2.5 tonnes of input the adsorption was virtually 100% (effluent < 4 pCi/L). The leakage currently averages about 15 pCi/L, although analytical feedback indicates considerable variation, from < 4 pCi/L to ~30 pCi/L radium content. The test procedure is on-going.

Reports:

- K.E. Haque, "The leachability of radium from uranium ores"; Division Report MSL 86-21 (OP&J).

- K.E. Haque, "Acid chloride leaching of Midwest Lake uranium ore"; Division Report MSL 86-66 (J).

- K.E. Haque and J.E. Laliberté, "Counter-current acid leaching of a low-grade and a high-grade uranium ore"; Division Report MSL 85-109 (J).

Standards and Specifications

- **Project 30.69.01:** Reference Materials
  Project leader : C.W. Smith

Objective:

To prepare and certify samples of ores, concentrates, metals and related materials for use as compositional reference materials, by means of interlaboratory and in-house programs. The compilation of methodological information from these programs is an important ancillary benefit to CANMET and the analytical community. In 1986/87, The Canadian Certified Reference Materials Project (CCRMP) distributed approximately 1500 units of reference materials to users in Canada and abroad generating a revenue of approximately $124,000.

CCRMP strives to fulfill the demand from Canadian industrial, commercial and research laboratories for geological materials. CANMET through CCRMP offers both the expertise and facilities and the continuity and impartiality that are essential for long-term credibility and public acceptance of reference materials. Most industrialized nations have similarly assigned the production of reference materials to government institutions.

(a) Current status

Certification assessment and documentation was completed for six new reference materials in the review period. Gold ore reference materials MA-1a, MA-2a and MA-3, vegetative radionuclide reference materials CLV-1 and CLV-2 and secular equilibrium uranium ore CUP-1 were made available for sale through CCRMP. Assessments and documentation for a suite of seven cast zinc/aluminum alloys (NZA-1 to NZA-7) and a thorium/lanthanide bearing britholite ore (OKA-2) are approaching completion.

In this period, industrial, government and commercial analytical laboratories continued to contribute expert measurements for the certification programs of CCRMP. Analyses by the Chemical Laboratory, MSL, provided critical information to assess the composition and homogeneity of candidate reference materials as well as providing expert laboratory measurements for the certification programs. CCU-1a, a candidate copper concentrate reference material, was prepared and distributed to thirty-five laboratories for measurements of eighteen component elements. Uranium concentrate material CUP-2 was prepared and distributed to eighteen laboratories for measurements of twenty components which are subject to specifications in commercial transactions. A zinc concentrate material, CZN-2, was prepared as a candidate reference material for a future program.

Additionally, CCRMP provided expertise and facilities for the production of reference materials at MSL for external agencies:

- Eleven powdered electrolytic bath reference materials were prepared for Alcan International Ltd., Arvida Research Laboratories.

- A thorium radiometric reference material (RGTh-1) was prepared and characterized for the International Atomic Energy Agency, Vienna, Austria.

- Four lake sediment reference materials were prepared for the National Water Quality Research Institute, CCIW, Burlington, Ontario.

- An ocean sediment reference material was prepared by the Analytical Chemistry Division, National Research Council, Ottawa.

- A candidate National Compressibility Cement Standard presently undergoing certification by the Canadian Standards Association was stocked pending future availability through CCRMP.

Staff of the Extractive Metallurgy Laboratory, MSL, provided essential statistical expertise and computing support for the Reference Materials Project. They additionally provided training in the application of statistical methods for reference material assessment to a visiting scientist from the Centre for Mineral & Energy Technology (CETEM), Rio de Janeiro, Brazil, in this period. A benefit to CANMET of this collaboration was the conversion of a statistical computing package from main-frame to personal computer format.

(b) International Committee on Reference Materials ISO/REMCO (Committee on Reference Materials)

This ISO Council Committee is responsible for the development of ISO Guides on all aspect of reference materials. Two MSL officers serve on this committee. The preparation of ISO Guide 33, "The uses of reference materials for assessment of measurement procedures", was completed during the year.

(c) Cordierite

Sample preparation for measurement of thermal diffusivity of Cordierite, a prospective thermal transport standard reference material proposed by the Centre National de la Recherche Scientifique, University of Orleans, was partially completed. Thermal measurements are in progress.

Electrical resistance measurements of POCO AXM-5Q1 graphite, a prospective thermophysical properties standard reference material proposed by the U.S. National Bureau of Standards, were completed.

Contracts:

Supply and Services Canada contracts 23440-6-9051/01-SQ to /06-SQ "Analytical measurements for the certification of uranium concentrate reference material CUP-2"

/01-SQ: Nuclear Activation Services Ltd., Hamilton, Ontario

/02-SQ: Kamloops Research and Assay Laboratory Ltd., Kamloops, British Columbia

/03-SQ: Saskatchewan Research Council, Saskatoon, Saskatchewan

/04-SQ: X-Ray Assay Laboratories Ltd., Don Mill, Ontario

/05-SQ: Bondar-Clegg and Company Ltd., Ottawa, Ontario

/06-SQ: Barringer Magenta Ltd., Rexdale, Ontario

Scientific Authority for above: J.L. Dalton

Reports/Publications:

- J.L. Dalton and W.S. Bowman, "CUP-1 - A certified uranium reference ore", CCRMP 86-2E.

- J.L. Dalton and W.S. Bowman, "Vegetative radionculide reference materials"; NUTP-4E.

- J.L. Dalton and C.E. Dunn, "Radionuclide-rich spruce twigs and needles as analytical reference materials"; Division Report MSL 86-140 (J). (Accepted for publication in J Radioanalytical and Nuclear Chemistry).

- V.V. Mirkovich, "Electrical resistance anisotropy of a Poco AXM-5Q1 graphite"; Division Report MSL 86-126 (J).

- C.W. Smith, H.F. Steger and W.S. Bowman, "MA-1a, MA-2a, MA-3: Certified gold reference ores"; CCRMP 86-1E.

- C.W. Smith, H.F. Steger and W.S. Bowman, "The certification of thorium and uranium concentrations in CCRMP reference materials OKA-2"; Division Report MSL 86-154 (IR).

• Project 30.69.02: Analytical Methodology
Project leader : J.C. Hole

Objective:

To develop and improve analytical methods, techniques, and laboratory facilities, mainly in support of CANMET programs, and to participate in working groups and/or serve on committees of national and international organizations which develop and disseminate information on standard analytical methods.

1. Analytical research and method development

(a) Determination of arsenic in ores, concentrates and related materials by graphite-furnace atomic-absorption spectrophotometry

A graphite-furnace method, involving the use of palladium and thiourea as matrix modifiers, has been developed for the determination of about 0.2 µg/g or more of arsenic in ores, concentrates, rocks, soils and sediments after separation of arsenic from matrix elements by cyclohexane extraction as the xanthate from 8-10 M hydrochloric acid.

(b) Determination of free thiourea in gold leach solutions

A semi-quantitative method, based on the reaction between nitrous acid and thiourea to form thiocyanic acid and the ultimate measurement of the iron (III) thiocyanate complex, has been applied to the determination of unreacted thiourea in leach solutions from the processing of chalcopyrite and arsenipyrite concentrates.

(c) Analysis of anode slimes

The conventional fire-assay fusion step has been modified to allow the determination of gold and silver in anode slimes containing large amounts of selenium and lead. An acid-decomposition procedure has also been developed for these materials to allow the determination of certain elements, without loss, by plasma spectroscopy.

(d) Determination of gold and silver in Mint sweeps

The gravimetric method previously developed for the determination of gold and silver in sweeps from the Royal Canadian Mint's gold refining process has been improved and made more efficient. The method has been applied to numerous samples.

(e) Determination of rare-earth elements in steels and advanced materials by high-performance dynamic ion-exchange chromatography

Dynamic ion-exchange HPLC methods are being investigated for the determination of about 1 µg/g of neodymium, praseodymium, cerium and lanthanum in steels, non-ferrous alloys and advanced materials without prior separation or preconcentration. These elements have also been determined, at the 25% level, in supermagnetic alloys.

(f) Determination of rare-earth elements in ores by dynamic ion-exchange chromatography

Dynamic ion-exchange chromatography has been applied directly to the rapid separation and determination of the rare-earth elements and yttrium in various ores after acid decomposition. By optimization of the instrumental parameters, these elements can be determined in the presence of uranium, thorium and various other metal ions.

(g) Determination of low molecular weight organic acids in lysimeter leach solutions by high-performance liquid chromatography

Reversed phases coated with a "permanently" sorbed ion exchanger, coupled with detection by indirect ultraviolet absorption, have been used for the determination of 0.1 - 0.3 x 10^{-3} M acetic, lactic, propionic and pyruvic acids in leach solutions dereived from studies of the use of biological oxygen barriers on the surface of mine tailing deposits. To improve the determination, prior separation of sulphate ion on a concentrator column is being investigated.

(h) Application of gas chromatography to the analysis of solvent extraction products

Capillary gas chromatography has been investigated for the detection of oxidation and decomposition products in isodecanol and diethyleneglycol dibutylether phases from solven extraction studies on the separation of gold.

(i) Analysis of organic solutions by X-ray fluorescence

An internal standard method has been developed for the direct determination of elements of atomic number greater than 21 in organic solutions. Calibration problems imvolve the availability of suitable calibration materials and methods for preparing suitable calibration solutions.

(j) Fission track technology

Methods, involving neutron activation, chemical etching and the counting of fission tracks, have been developed for the determination of geological age, and also for sub-ppb concentrations of uranium in aqueous solutions, by fission track dating. Most minerals, except for zircon, can be dated by this method.

(k) International Atomic Energy Agency laboratory manual

MSL Chemical Laboratory staff are participating on a committee to prepare an IAEA laboratory manual on the analytical chemistry of the uranium exploration, mining and milling industry. Eight reports describing methods to be included in this manual have been prepared.

(l) Inductively-coupled plasma atomic-emission spectrometric analysis

A second ICP sequential spectrometer acquired during the review period has been put into routine analytical service. It allows a much greater sample throughput, particularly for multi-element analysis, than the first spectrometer. A microwave sample preparation technique for the determination of arsenic and antimony has greatly reduced sample preparation time, and improved instrumental efficiency.

(m) Computerized LIMS system for the Chemical Laboratory

Plans for the installation of a network of microcomputers to link each of the sections in the Chemical Laboratory are proceeding on schedule; quotations have been received for the installation of the initial part of the network. A contract with Bureau of Management Consulting of Supply and Services Canada to provide a single user data management program is completed. The system will replace the current analysis report system and provide on-line access to the current status of all samples, to electronic mail service and to a Chemical Stores inventory system.

(n) Fourier transform infrared spectroscopy system

A Digilab FTS-40 with external sample chamber was acquired and installed. The equipment was aligned and tested using samples from various projects and the applicability of the software to the required manipulation of data was examined. The performance of the system is satisfactory.

(o) Infrared examination of precipitates from thiourea leaching solutions

Comparisons with prepared products of thiourea oxidation showed that the organic moiety complexed to copper in the precipitate was thiourea. The metal was complexed through the sulphur atom of the thiourea in a compound that also contained sulphate ion. Some other materials of interest in solvent extraction studies of thiourea complexes were examined by infrared spectroscopy.

(p) Computerized information system in the Chemical Laboratory

A new project number file and a routine to validate and correct numbers on data entry were written to reflect project number changes for the 1986/87 fiscal year.

Reports:

2. Standards development

(a) ISO/TC 102 (iron ores)

Again this year, CANMET has made substantial contributions to this International Organization for Standardization technical committee.

(i) SIO/TC 102/SC 1 (sampling)

In addition to the continuing review of various standards relating to iron ore sampling, the subcommittee is also investigating the possible application of "variograms" for iron ore sampling. An MSL officer is representing Canada on the working group set up for this investigation.

(ii) ISO/TC 102/SC 2 (chemical analysis)

An MSL officer is chairman of this subcommittee, and collaborates in the on-going investigations. Two inter-laboratory studies have been completed, and numerous technical documents have been reviewed.

(iii) ISO/TC 102/SC 2/WG 12 (chemical analysis - working group on statistics)

An MSL officer serves as convener of this working group, which evaluates statistically all international tests conducted by the subcommittee. Eight sets of international tests were completed and evaluated. The results of these tests were instrumental in the acceptance, in principle, of these analytical methods as ISO standards.

(b) ISO/TC 183 (copper, lead and zinc ores and concentrates)

Two MSL officers are members of the Canadian Advisory Committee to this ISO Technical Committee.

(i) Chemical analysis

Two CANMET analytical methods, for the determination of gold and silver in lead and zinc concentrates, have been submitted to be considered for testing as international standards.

(ii) ISO/TC 183/WG 10 (statistical evaluation of test programmes)

An MSL officer serves as convener of this working group. Six international tests at the standardization stage have been completed; the results have been statistically evaluated and reported.

(c) ISO/TC 69 (application of statistical methods)

This ISO technical committee is responsible for the development of generic standards on the application of statistical methods for use by other technical committees within ISO. An MSL officer serves as the Canadian representative to the working group on the revision of ISO 5725, a generic standard for the determination of accuracy of test methods. The same officer serves also as chairman of the Canadian Advisory Committee on subcommittees 3 and 6 as well as convener of SC 6/WG 4 on reference materials.

(d) International data collection and storage

MSL is the international centre for analytical data generated by both ISO/TC 102 and ISO/TC 183. The data bases, and also programs for retrieval and statistical evaluation of the data, are created and maintained by MSL personnel using the facilities of the EMR Computer Services Centre.

Reports:

- D.J. Barkley, K.N. Villeneuve and T.E. Dahms, "Dynamically and permanently coated columns for liquid chromatographic determination of anionic species in samples from environmental control process"; Division Report MSL 86-111 (OP).

- P.E. Moloughney, "Determination of precious metals in a byproduct from the Royal Canadian Mint"; Division Report MSL 86-7 (CR).

- R. Sutarno, "ISO/TC 183 Meeting, Sydney, Australia 1986-04-27 to 1986-05-02. Report of WG 10 convener"; Division Report MSL 86-70 (TR).

- R. Sutarno, "ISO/TC 102/SC 2 - 13th International Meeting Tokyo, Japan, 1986-11-9/14"; Division Report MSL 86-168 (TR).

- R. Sutarno and W.S. Bowman, "ISO/TC 183/WG 4A - Determination of copper in copper concentrates by electrogravimetric method - statistical evaluation of international test data 1984-1986"; Division Report MSL 86-30 (IR).

- R. Sutarno and W.S. Bowman, "ISO/TC 183/WG 1A - Determination of gold and silver in copper concentrates by fire assay method - statistical evaluation of international test data 1984-1986"; Division Report MSL 86-39 (IR).

- R. Sutarno and W.S. Bowman, "ISO/TC 183/WG 10 - Determination of precision of analytical procedures by international trials - tests for outliers"; Division Report MSL 86-52 (IR).

- R. Sutarno and W.S. Bowman, "ISO/TC 102/SC 2/WG 19B - Determination of vanadium content in iron ores by BPHA spectrophotometric method - statistical analysis of international test data - 1986"; Division Report MSL 86-99 (IR).

- R. Sutarno and W.S. Bowman, "ISO/TC 183 - copper, lead and zinc ores and concentrates - international tests during the period of 1984-1986"; Division Report MSL 86-100 (OP).

- R. Sutarno and W.S. Bowman, "ISO/TC 102/SC 2/WG 25B and WG 28A - Determination of phosphorus content in iron ores by molybdenum blue spectrophotometric methods - statistical analysis os international test data - 1986"; Division Report MSL 86-116 (IR).

- R. Sutarno and W.S. Bowman, "ISO/TC 102/SC 2/WG 21B - iron ores - determination of nickel and/or chromium content by flame atomic absorption method statistical analysis of international test data - 1986"; Division Report MSL 86-128 (IR).

- R. Sutarno and W.S. Bowman, "ISO/TC 102/SC 2/WG 26B - iron ores - determination of manganese content by atomic absorption spectrometric method statistical analysis of international test data - 1986"; Division Report MSL 86-130 (IR).

• **Project 30.69.03:** Aggregate/Concrete Testing and Standards
Project leader : G.G. Carette

Objective:

To provide technological expertise and information for Canadian and international standards writing organizations concerned with aggregates and concrete, by performing development work on in-situ tests, NDT methods and other tests, by coordinating the CSA Sample Comparative Cement testing program, by organizing conferences on the use of NDT and new concrete materials and by participating in committees of the CSA, ACI, ASTM, ISO, etc.

Aggregates and concrete testing and standards contribute much to ensuring that concrete will perform as specified in construction projects, thus protecting public interest and safety.

(a) Joint comparative CSA Cement Sample Program

At the request of the Committee on Hydraulic Cements of CSA and the Canadian cement industry, a joint project was initiated at the end of 1978 between Canadian cement testing laboratories and CANMET to assess existing cement specifications and testing methods in Canada. CANMET is coordinating the program and is in charge of the overall organization, including the preparation and distribution of test samples and the compilation, analysis and publication of test data. The cement test samples for the program are obtained from the current production of a cement plant selected at random from among the participating companies. Cement sample No. 41 was distributed to 25 laboratories in the country.

Also, at the request of the above committee, CANMET has initiated a new National Cement Reference Sample program for the purpose of providing the industry with a means of verifying their cement testing procedures. The reference sample will become available in the summer of 1987 and it will be distributed through the Canadian Certified Reference Materials Project of CANMET.

(b) 2nd International Conference on the use of fly ash, silica fume, slag and natural pozzolans in concrete

CANMET, in association with the American Concrete Institute, U.S.A. sponsored the 2nd International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete in April 1986 in Madrid. The 5-day conference was a great success with more than 450 delegates from 36 different countries attending. A total of 120 technical papers were presented, 78 of which were published in the proceedings (2 volumes of about 800 pages each).

(c) International workshop on concrete for offshore structures

CANMET also sponsored a very successful international workshop on "Concrete for Offshore Structures" in September 1986 in St. John's Nfld. The 2-day workshop which dealt mainly with problems associated with the design and construction of offshore structures, attracted more than 120 participants from both North American and Europe.

(d) International workshop on condensed silica fume in concrete

The final program of an international 2-day workshop on "Condensed Silica Fume in Concrete" was released. The workshop to be co-sponsored by CANMET will be held in Montreal in May, 1987 and will include 24 technical presentations.

Planning is also underway to co-sponsor a 2-day workshop on "Slags in Concrete" to be held in Hamilton in October 1987.

- **Project 30.69.04:** Thermal Shock-Resistant Cermaics
  Project leader : V.V. Mirkovich

Objective:

To obtain a better understanding of thermal shock failures and to validate CANMET-formulated quantitative correlation for predicting thermal shock resistance of brittle materials.

The validity of CANMET-formulated quantitative correlation was demonstrated in previous studies on mineral and ceramic materials. To extend the scope of this correlation six types of commercial refractory bricks, having a high thermal shock resistance, were tested. The results have demonstrated that five of the six bricks were substantially different from the previously studied materials. The correlation between the thermophysical properties and the strength loss due to thermal shocking was only partially successful. To obtain a clearer correlation the study should be expanded to cover a larger variety of brittle materials.

Report:

- V.V. Mirkovich and K.E. Bell, "Thermal shock resistance study of six refractories"; Division Report MSL 86-171 (J).

Byproduct Recovery

- **Project 30.77.01: Silver Recovery in the Zinc Industry**
  Project leader : J.E. Dutrizac

Objective:

To increase the recovery of silver in Canadian zinc plants to >75%. This will be achieved by elucidating the behaviour of silver in conventional and proposed zinc circuits and by determining the chemical and mineralogical balances of silver in these operations. An equally important objective will be to develop at the bench and mini plant scales, new processing technology to increase silver recoveries in zinc plants by 1987. The success of the project will be measured in terms of scientific reports and of new processing concepts to increase silver recoveries.

Canada in the world's largest supplier of zinc concentrates and is also a major producer of zinc metal. All Canadian commercial zinc concentrates contain potentially recoverable quantities of silver. Current silver recoveries in Canadian plants range from 0 to >90%. Because of the value of the silver byproduct, much work has already been done on silver recovery, and many investigations are in progress but with limited success to date. Thus, there is a genuine need for a thorough and critical examination of the whole problem of silver deportment and recovery in the zinc industry - commencing with the ore and proceeding through the various processing steps to the final products and/or residues.

(a) Mineralogical Investigations

Good progress continues to be made in the mineralogical characterization of silver in zinc concentrates and residues. Proton microprobe results for trace Ag in the complex sulphide ores of New Brunswick have defined the levels of Ag substitution in sphalerite and associated galena. The galena in this ore contains 740 ppm Ag and accounts for ~30% of the total Ag; tetrahedrite is the major Ag carrier in the zinc concentrates. Further studies on the deportment of silver are planned at the Max Planck Institut fur Kernpysik, Fig. 9. The various leach residues from the oxygen pressure leaching of a pyritic Zn-Pb-Cu-Ag concentrate also have been characterized. Silver reports in the final residue mostly as unleached argentian tetrahedrite and as precipitated silver-bearing lead jarosite. Other major Ag carriers are $PbSO_4$, unleached galena and basic iron sulphate gel particles. Treatment of the residues with SO_2 converts the jarosite to $PbSO_4$ and to complex sulphide-sulphate capsule-like structures rimmed by silver sulphide.

Flotation concentrates made by Vieille-Montagne, Belgium, were examined and compared to similar products from Canadian feeds. The silver occurs mostly as silver sulphide and silver chloride, and is associated with unleached sphalerite, sulphur and silica gel. Silver-bearing jarosite was present in the flotation tailing, and was the major silver carrier in this fraction.

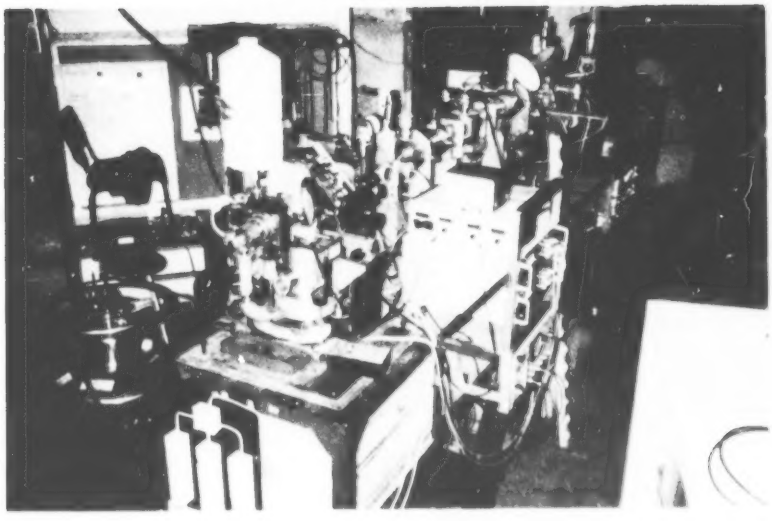

Fig. 9. The target chamber at the end of the beamline of the proton microprobe at the Max Planck Institut fur Kernpysik, West Germany. The first Canadian proton microprobe is scheduled for completion in the Fall of 1987 at the University of Guelph.

(b) Silver in zinc processing

Silver can be leached from zinc residues by thiourea, and the reaction of thiourea with Ag metal has been studied. Rapid rates are observed that increase with increasing temperatures. The effects of the concentrations of thiourea, Fe^{2+} and Fe^{3+} on the reaction rate were reported and the simultaneous decomposition of the thiourea leaching medium was studied.

Silver which passes into solution in a zinc plant often is precipitated as a jarosite-type compound, and the behaviour of Ag during the precipitation of natrojarosite and plumbojarosite was determined. Extensive losses of Ag to the jarosite phase always were observed, with the silver replacing either Na^{+} or Pb^{2+} in the structure. It was concluded that silver losses into commercial precipitates made in sulphate media would always be significant. By contrast, jarosite precipitates made from silver-bearing chloride processing solutions are essentially silver-free.

As zinc processing solutions also contain chloride ion, the solubility of AgCl in simulated zinc processing solutions has been determined. The solubility increases with temperature and H_2SO_4 concentration, but decreases significantly with increasing chloride concentrations because of the common ion effect. A report on this aspect is being drafted.

(c) Zinc electrowinning

As part of a continuing project to optimize zinc electrowinning from acid sulphate electrolytes, the effects of As^{3+} and As^{5+} on the current efficiency and deposit morphology have been determined. Also, the effects of 15 other impurities and their interactions with glue under commercial electrorefining conditions were characterized.

Efforts to recover silver from zinc leach residues have focussed on flotation and thiourea leaching. Studies are underway to determine the effects of flotation reagents and thiourea on zinc electrowinning from commerical electrolytes. A paper describing the effect of thiourea on the current efficiency, polarization behaviour and deposit morphology-orientation has been prepared. Work on the identification of methods to overcome the detrimental effects of thiourea, and to a lesser extent glue, is nearing completion.

Contracts:

- Reqn. 4-9295 "Computation of PIXIE analytical data", University of Guelph. S.A. - L.J. Cabri

- Reqn. 5-9045 "Recovery of silver from zinc plant residues - Phase II", Noranda Research Centre. S.A. - J.E. Dutrizac

- Reqn. 5-9129 MDA "Gold-silver recovery from zinc pressure leach residues - Phase I", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W. Craigen.

- Reqn. 5-9220 MDA "Metal recovery oxide residues", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W. Craigen.

- Reqn. 5-9264 MDA "Gold-silver recovery from zinc pressure leach residues - Phase II", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W. Craigen.

- Reqn. 6-9191 MDA "Gold-silver recovery from zinc pressure leach residues - Phase III", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W. Craigen.

Reports:

- L.J. Cabri, "The mineralogy of precious metals: New developments and metallurgical implications: Presidential address"; Division Report MSL 86-55 (OP&J).

- T.T. Chen and J.E. Dutrizac, "Mineralogical characterization of the residues of the two-stage oxygen pressure leaching of a pyritic zinc lead copper silver concentrate with SO_2 reduction of the jarosite fraction"; Division Report MSL 86-94 (J).

- J.E. Dutrizac and J.L. Jambor, "Behaviour of cesium and lithium during the precipitation of jarosite-type compounds"; Division Report MSL 86-57 (J).

- J.E. Dutrizac and J.L. Jambor, "The behaviour of silver during jarosite precipitation"; Division Report MSL 86-113 (J).

- J.E. Dutrizac and J.L. Jambor, "The behaviour of arsenic during jarosite precipitation: the mechanism of arsenic precipitation"; Division Report MSL 86-133 (J).

- J.H.G. Laflamme and L.J. Cabri, "Silver and bismuth of galena from the Brunswick No. 12 Mine"; Division Report MSL 86-91 (IR).

- J.H.G. Laflamme and L.J. Cabri, "Silver and antimony contents of galena from the Brunswick No. 12 Mine"; Division Report MSL 86-138 (IR).

- D.J. MacKinnon and J.M. Brannen, "Characterization of impurity effect in zinc electrowinning"; Division Report MSL 86-148 (J).

- D.J. MacKinnon, J.M. Brannen and R.M. Morrison, "The effect of thiourea on zinc electrowinnings from industrial acid sulphate electrolyte"; Division Report MSL 86-62 (J).

- R.M. Morrison, "The effect of thiourea on the dissolution kinetics of silver metal in ferric sulphate-sulphuric acid media"; Division Report MSL 86-159 (J).

- L.K. Tan and J.E. Dutrizac, "Solubility determination of arsenic III and arsenic IV in leaching solutions containing zinc sulphide by ion chromatography with triple step pulse potential electrochemistry and conductivity detectors". Division Report MSL 86-40 (J).

• Project 30.77.02: Non-ferrous Metallurgical Slags
Project leader : A.H. Webster

Objective:

To develop methodology to reduce the loss of valuable metals such as nickel, copper, cobalt and precious metals and to increase the rejection of undesirable elements such as arsenic, bismuth and antimony into slags through better understanding of the factors affecting metal losses to slags, and to recommend practices for control.

Most concentrates of copper, nickel and lead sulphide ores are treated by pyrometallurgical smelting. Many of the concentrates sent for smelting contain minor amounts of valuable metals, for example, cobalt, precious metals, molybdenum and zinc, some of which may be lost to the slag. Methods for decreasing these losses or for recovering the metals from the slag before it is discarded would help conserve Canadian mineral resources by increasing recoveries from the ores.

(a) Extraction of valuable metals from industrial slags into high-iron matte

Favourable results were obtained when industrial discard slag from nickel smelting operations was treated with pyrrhotite mineral at 1250°C in an oxygen-free atmosphere to recover Ni, Co and Cu values. To raise the levels of these valuable elements in the iron sulphide matte in order to facilitate their subsequent recovery, the matte was recycled with fresh slag. After four recyclings, the level of Ni increased from 0.34% to 2.27%, of Co from 0.22% to 0.55% and of Cu from 0.55% to 3.00% in the matte. Electron microprobe analyses verified this trend and indicated that the elements were present in two distinct phases in the solidified matte; an iron-rich alloy containing about 60% Fe, 30% Ni, 6% Co and 2% Cu, and a bornite-like phase containing Fe, Cu and S.

Two more series of experiments were conducted in an attempt to enhance the reversion of elements to the iron sulphide matte. The first involved mixing of various amounts of carbon powder, as a powerful reducing agent, with the slag/pyrrhotite mixture. In the second, metallic iron was used instead of carbon. Preliminary results indicated that, in both cases, the formation of relatively larger amounts of the metal alloy phase was evident.

(b) Selenium distribution in Cu/Cu_2O melts

The presence of high concentrations of selenium in blister copper was found to cause difficulties in the fire refining stage and results in alterations of some properties of the final product. In the copper production process, most of the selenium resides in the matte during the smelting operation. It was also found that selenium concentrates in the last portion of the unconverted matte. To reduce the level of selenium in the final product, it was suggested that the last portion of the unconverted matte be oxidized separately to Cu_2O and Cu after withdrawing blister copper (with low selenium content) at the early stages of converting. The Cu_2O/Cu melt would then be treated to recover selenium.

In the present study, the distribution coefficient of selenium in Cu_2O/Cu melts was determined experimentally. Mixtures of Cu_2O, Cu and Se were melted at 1280°C in argon and samples were collected, using a specially developed technique, from the metal and the oxide layers to be analysed chemically and examined by scanning electron microscopy (SEM). The distribution coefficient, defined as selenium content of oxide/selenium content of copper, was found to be around 2. The SEM results indicated that selenium in the solidified material was associated mainly with the oxide phase. However, the solubilities of copper oxide in the molten metallic copper phase, and of copper in the molten copper oxide phase, are substantial and therefore difficulties may be encountered in trying to separate the copper selenide phase and hence the selenium.

Contracts:

- Reqn. 3-9172 "To develop a clean smelting process for highly roasted

copper-nickel calcines and to improve metal recovery", Falconbridge Ltd. S.A. - A.H. Webster.

Environmental Controls

- Project 30.86.01: Tailings Characterization and Control Mechanisms
  Project leader : G.M. Ritcey

Objective:

To contribute to the development of methodology for the effective control and disposal of potential environmental contaminants discharged from mine/mill operations.

It is becoming increasingly evident that the existing methods for the containment and disposal of mine-mill wastes are not without environmental difficulties related to acid generation and the release of many other potentially noxious elements. With the development of newly discovered deposits containing a wider range of potential pollutants these difficulties may become more serious.

The most desirable approaches to resolving these problems are those which employ well-known unit processes which can be readily substituted for those presently in use, or added on to existing processes.

CANMET's role will include contributions to the development of new processing steps for the removal of pollutants in mills prior to discharge, the development of methods for the treatment of effluents and the development of methods for containment technology.

(a) Mineralogy

Samples of size fractions of cores taken from a subaereal lysimeter test were evaluated to compare with surface chemistry, radiometric analysis and magnetic susceptibility. The report is expected in 1987.

(b) Lysimeter tests

At present, 32 separate lysimeter leaching tests are in operation to evaluate the effectiveness of placing wetland (bog) vegetation on the surface of pyrite containing tailings for the purpose of arresting sulphuric acid generation. Inhibition of bacterial sulphide mineral oxidation, which is the primary cause of sulphuric acid generation, is manifested by effluents from the test lysimeters of near neutral pH containing low concentrations of iron and sulphate. Results to date indicate that sulphuric acid generation is completely arrested by 20-30 cm of wetland vegetation placed on the surface of the tailings and that a water table near the tailings/soil interface is necessary to arrest sulphuric acid

generation. Tailings that responded to the treatment were Elliot Lake, Waite Amulet, Brunswick, Noranda Quemont, Noranda pyrite. The Thompson tailings did not turn acidic, and the Sheridan and Cominco remained acidic. Two additional lysimeters, high and low pyrite, are being examined to determine whether acidic seepage from a site entering a bog-covered tailings will be altered in pH. Preliminary data suggest that this may be the case.

(c) Deep water disposal

Two lysimeters were started during 1985 to simulate deep water disposal of tailings. Columns are 60 cm diameter x 6 m high each containing 0.25 tonne Elliot Lake tailings in one column and Noranda pyrite (92%) in the other. The columns are filled with Ottawa River water. Sampling is conducted at different depths of the columns. The data are compared with those from control lysimeters at normal deposition conditions.

After 26 weeks the Elliot Lake test had stabilized at a neutral pH; acid generation had commenced in the control. Bacteria population was stable at 10^5 - 10^6 cells/mL.

After a further 52 weeks the pH still was near neutral and the acid generation in the control test was then pH 3.5. The ^{226}Ra in the water column was decreased from ≈100 to ≈50 pCi/L. In the Noranda pyrite test, the pH had stabilized at pH 4 after 26 weeks but after a further 52 weeks the pH was 3.2, while the control test was pH 3.0. There was little change in bacteria population at 10^3 - 10^4 cells/mL.

(d) Salt and clay capping of pyritic wastes

During the construction of the Halifax International Airport, Transport Canada excavated ≈40,000 tonnes of pyritic shale and overburden which are stockpiled on the property. With weathering an acidic drainage developed which subsequently leached high concentrations of metal ions from the waste. Transport Canada decided to encapsulate this waste in clay in order to reduce or prevent the acidic drainage. Laboratory studies were conducted using a combination of run-of-mine sodium chloride and clay as a capping material. This concept is currently being tested on the pyritic wastes at the Halifax Airport.

(e) Mineralogical studies on tailings

Samples of Waite-Amulet tailings were examined by mineralogical techniques to identify the change in minerals with depth during the weathering process. Briefly, the quantity of sulphide minerals increases from the oxidation zone to relatively constant quantities in the reduction zone. There was no physically distinct hardpan in the transitional zone.

(f) Analytical development

i) Radon-222 emanation studies

A study of the emanation rate of radon from radium-containing materials has been completed. Variables investigated were grain size, pelletizing of powders, intergranular medium and covering layers. It was found that dry covering material saturated with water reduces the emanation almost to background level. A practical aspect of the work is the measurement technology. The escape of radon from solids is caused by recoil during the redioactive decay of the parent radium atom.

ii) Analysis of tailings samples

Analytical methods for the determination of readily-soluble constituents (sulphate, calcium and iron) of selected tailings samples from Noranda's Waite-Amulet deposit have been evaluated. Total sulphate, elemental sulphur and pH have also been determined.

Contracts:

- Reqn. 5-9156 "Microbial control of tailings dump leaching", University of Ottawa. S.A. - W.D. Gould

- Reqn. 23376-6-4442/01 - SQ "Susceptibility and magnetic property measurements on selected samples from Sheridon and Waite-Amulet mine tailings", Morris Magnetics. S.A. - G.M. Ritcey

Reports:

- R.G.L. McCready, "A review of the physical, chemical and biological measures to prevent acid mine drainage: An application to the pyritic Halifax shales"; Division Report MSL 87-3 (OP&J).

- R.G.L. McCready and J. Salley, "Perliminary results on the inhibition of pyrite oxidation by road salt and clay capping of Halifax pyritic shales"; Division Report MSL 86-129 (TR).

- W. Petruk and R.G. Pinard, "Mineralogical and image analysis study of samples from core WA20 of the Waite Amulet tailings"; Division Report MSL 86-87 (IR).

- Project 30.86.02: Tailings Management, Solution Transport and Contaminant Migration from Tailings

  Project leader : N. Davé (MRL)

Objective:

The objective is to develop an effective technology of tailings disposal and management to minimize environmental impact. For inactive tailings piles

the objective is to develop methods of tailings treatment, disposal and surface stabilization to reduce the detrimental effects of contaminant transport via surface run-off, groundwater infiltration as subsurface seepage and surface erosion by wind and water.

Achievements:

Under the Reactive Tailings (RATS) program, hydrogeochemical investigations of highly reactive sulphide tailings are being carried out at the Waite Amulet tailings site in Noranda, Quebec. Preliminary geophysical investigations including seismic, electromagnetic and electrical resistivity surveys were completed in 1985. The results showed an irregular bedrock topography with a clay layer of varying thickness underneath the tailings. Within the tailings, a hardpan layer of tailings exists above the water table which roughly marks the boundary between oxidized and unoxidized zones. Continuous solid core tailings samples were obtained at nine locations for physical, mineralogical and chemical analyses. At two more locations, tailings were sampled for bacterial counts, including iron oxidizing and sulphate reducing organisms. A total of 55 piezometers were installed in and around the tailings to monitor groundwater flow paths, tailings pore water chemistry and migration of contaminants. The pH and electrical conductance of the tailings pore water varied between 5-7.5 and 1,000 to 10,000 µs, respectively. Fe, Ca, Mg, Zn and SO_4^{-2} have been the major ionic constituents of tailings pore water. Results to date have indicated that because of the reduced permeability of the clay layer a good aquitard has developed with the result that the tailings pore water drains through the impoundment dams. Oxidation of the near neutral tailings pore water also takes place as it passes through shallow zones near the dams.

Mineralogical, physical and chemical analyses were conducted at Ottawa (MSL) and at the Elliot Lake Laboratory.

Monitoring, sample collection and analysis continued during 1986, and several new wells were drilled before winter set in.

Results of on-going work were presented at the 1986 National Symposium on "Surface Mining, Hydrology, Sedimentology and Reclamation" in Lexington, Kentucky. This presentation was recognized by an award for outstanding technical paper at the Conference.

Future Work:

The collaboration between the Elliot Lake Laboratory, Noranda Research Centre, Pointe Claire, P.Q., and Noranda Mines Ltd., Noranda, P.Q., will be continued.

With the cooperation of Denison Mines Lts., and Rio Algom Mines in Elliot Lake, studies on tailings area water budget and future close-out options will be pursued.

Reports:

- N. Dave, T.P. Lim, R. Siwik and R. Blackport, "Geophysical and biohydrogeochemical investigations of an inactive sulphide tailings basin, Noranda, Quebec"; Division Report MRL 86-99 (OP&J).

- Project 30.86.03: Water Pollution Control
  Project leader : B.H. Lucas

Objective:

To establish technology for the control of water pollution to meet the standards set by regulatory agencies for the mining and processing of minerals by identifying potential problems and examining methods for the removal of environmental contaminants from metallurgical processes liquid waste streams.

The Mineral Sciences Laboratories have had an interest for many years in the treatment of liquid effluents from the mining industry. These include heavy metals, cyanide, arsenic and thiosalts. Priority will be given to the removal and containments of sludges from the treatment processes to clean up liquid effluents of arsenate, thiosalts, cyanide, heavy metals and other undesirable contaminants.

(a) Biotechnology for effluent treatment

i) Biodegradation of cyanide

Assessment of the ICI fungal product indicated that it was suitable for degrading CN^- at concentrations greater than 50 ppm but was ineffective in reducing effluent concentrations of cyanide which are initially less than 50 ppm due to the high Km of the enzyme. Further, the fungal product only degrades free cyanide but is not effective in degrading cyanide-metal complexes.

ii) Bacterial precipitation of arsenic

Arsenic must be reduced to a level of < 0.5 ppm in mill effluents prior to release to surface waters. A study was conducted to assess the feasibility of co-precipitating arsenic and iron under anaerobic conditions with bacterially generated H_2S, thereby forming insoluble arsenopyrite. Experimentally solutions initially containing 100 ppm of arsenic could be reduced by precipitation of arsenopyrite down to a concentration of 10 ppm. Unfortunately, using this bacterial approach the arsenic content of a solution could not be reduced to less than 10 ppm. As a result, this project was terminated as chemical precipitation of arsenic is more effective.

(b) Impurity behaviour during iron precipitation

Hydrometallurgical processing solutions often contain modest concentrations of arsenic and phosphorous, and it is possible to control these impurities, at least in part, during iron precipitation. Consequently, a systematic study of the behaviour of arsenate and phosphate during jarosite precipitation has been undertaken. Large amounts of arsenate are removed during jarosite precipitation, and the percentage elimination increases with increasing arsenic concentrations. The effects of solution composition, pH and reaction temperature on the precipitation in both sulphate and chloride media have been determined. The arsenate is invariably precipitated as scorodite, $FeAsO_4.2H_2O$. Although partly crystallized precipitates are formed at 100°C from chloride solutions, temperatures > 125°C are needed to form well crystallized scorodite from sulphate processing solutions. At lower temperatures, more soluble amorphous $FeAsO_4.xH_2O$ is produced. Two papers have been prepared on the behaviour of arsenic. Work is continuing on the behaviour of phosphate during jarosite precipitation, and initial results indicate that the behaviour of phosphate is much more complicated than that of arsenate.

(c) Acidification for cyanide elimination

The CANMET AVR cyanide recovery process (MRP/MSL 85-44 (IR)) is under development in response to industry and government requirements for a technically and economically viable solution to the gold mill waste water problem.

Chemical destruction of metallo-cyanide species is reagent intensive. Natural degradation is widely used but poses many uncertainties. For all destructive methods costs are unrecoverable. It is possible, at many mills, to offset environmental costs by recovering the cyanide for reuse.

The AVR method is currently being refined to increase the efficiency of dissociation of the cyanide constituents so as to recover all valuable components and produce environmentally safe waste water.

The following process steps are being intensively investigated:

a) pseudo-catalytic enhancement of air-induced metallo-cyanide dissociation

b) recovery of cyanide from acidified and aerated solution by ion exchange

c) process sludge treatment

d) reverse osmosis preconcentration

e) effluent polishing by sulphide adsorption, and by chemical addition

Four of these aspects have patentable elements. All steps are being integrated successfully into technically and economically viable process options which will enable the gold producer to achieve flexibility in

fitting this process into his plant requirements.

Water conservation is also an element of this technology. The process does not add, or create, undesirable water constituents. Chemically, only simple acidification is involved.

The possibility of utilizing the AVR process steps to enable the recovery of cyanide component of thiocyanate, for increased environmental protection and monetary regain, is also being investigated.

(d) Analytical development

- Determination of anionic species in gold mill barren effluent test solutions by high performance chromatography

Reversed phases coated with a "permanently" sorbed ion exchanger such as cetylpyridinium chloride, coupled with detection by indirect ultraviolet absorption, have been investigated for the determination of chloride, cyanate, sulphate, thiosulphate and thiocyanate in solutions derived from tests aimed at reducing cyanide in gold process effluents. Excellent resolution and sensitivity (~0.05 µg/mL) were obtained for the early eluting chloride and cyanate ions and for the more strongly retained sulphur species.

Contracts:

- Reqn. 5-9161 "Generation and stability of mine/smelting effluent sludges", Gionet, Mellor, Leibich Assoc. Ltd. S.A. - B.H. Lucas.

- Reqn. 5-9203 "Evaluation of the applicability of reverse osmosis technology to cyanide and base metals recovery from a gold mill barren bleed", Zenon Environmental Inc. S.A. - V. McNamara.

Reports:

- D.J. Barkley, T.E. Dahms and K.N. Villeneuve, "Dynamically and permanently coated columns for liquid chromatographic determination of anionic species in samples from environmental control process"; Division Report MSL 86-111 (OP&J).

- J. Dutrizac and J.L. Jambor, "The behaviour of arsenic during jarosite precipitation at 97°C"; Division Report MSL 86-131 (J).

- J. Dutrizac and J.L. Jambor, "The behaviour of arsenic during jarosite precipitation: The mechanism of arsenic precipitation"; Division Report MSL 86-133 (J).

- W.D. Gould, L. Beaudette and R.G.L. McCready, "Destruction of cyanide from gold mill effluents using enzymes"; Division Report MSL 86-105 (OP).

• **Project 30.86.04: Air Pollution Control**
Project leader : J.M. Skeaff

Objective:

To evaluate and where feasible to develop effective and acceptable methods for the monitoring and control of noxious elements encountered in Canadian pyrometallurgical processes. Investigations will focus on developing thermal data presently lacking for arsenides and arsenates, as well as methods for eliminating SO_2 from smelter off-gases.

The emissions of noxious elements and their compounds during pyrometallurgical processing of Canadian ores and concentrates is an area of concern to federal and provincial health and environmental protection organizations as well as to private industry. Of particular concern are non-ferrous roasting and smelting operations which result in emissions of SO_2 and of arsenic and mercury and in many cases small quantities of other toxic elements such as cadmium, selenium, tellurium and lead. There is a need for more definitive data on these trace elements in the concentrates and process streams, and on the form in which they are transported. Also required are data for modifying flowsheets or developing pollution abatement equipment for the economic removal and disposal or recovery of these ele- ments, in particular those associated with dusts from smelters which, due to economic or location factors, do not have an acid plant and thus constitute particular problems as to the roasting operations associated with the recovery of gold, silver, nickel and cobalt from arsenical ores.

(a) Thermochemical studies of arsenides and arsenates

Thermochemical and DTA studies are being conducted to determine the thermal properties of arsenides and arsenates (those of Ni, Fe, Cu, Co, Pb, Zn and Ca) at elevated temperatures in order to develop data which will enable the prediction of the behaviour of arsenic-bearing systems in pyrometallurgical processes, e.g. roasting, smelting, refining, etc.

An investigation of the thermochemical properties of certain arsenides is being conducted by an equilibrium electrochemical technique in which a partially stabilized ZrO_2-CaO electrolyte is employed in an oxygen concentration cell to measure galvanic potentials. To date, thermochemical data for Ag_3AsO_4 and $Ni_3As_2O_8$ as well as preliminary data for skutterudite [$CoAs_3$] have been obtained. The resulting data can be used to predict stable condensed phases and gas compositions occurring under roasting or other pyrometallurgical conditions.

Work has been initiated to determine the thermochemical properties of metallic arsenides by a novel electrochemical cell design in which pellets of two metallic arsenides and calcium arsenide are compressed on either side of a single crystal of calcium fluoride electrolyte. Oxygen must be rigidly excluded from the cell compartment. Preliminary results indicate that the cell exhibits reversibilty with respect to temperature. If successful, the

cell design should enable the determination of the decomposition pressures and thermochemical properties of metal pnictides such as the arsenides as well as metal chalcogenides. The resulting data can be used to predict stable condensed phases and gas compositions occurring under roasting or other pyrometallurgical conditions.

The oxidation of skutterudite [$CoAs_3$] is being investigated by differential thermal analysis and thermogravimetry. Results to date indicate that particle size, sample geometry and oxygen partial pressure all influence the oxidation process of natural skutterudite. X-ray diffraction analysis of the reaction products has indicated the formation of a complex mixture of arsenides and arsenates, due partially to the extensive substitution of iron and nickel in the naturally-occurring skutterudite [$Co(Fe,Ni)As_3$]. The resulting data can be used to predict the behaviour of skutterudite under roasting or other pyrometallurgical conditions.

A study of the oxidation and thermal dissociation of niccolite [NiAs] by thermogravimetry and concurrent differential thermal analysis in various atmospheres was completed. The results indicate that oxidation occurs in multiple stages due to the formation of a product layer at the surface of the niccolite particles. The dissociation process of the mineral took place by releasing arsenic and was found to influence the oxidation process to a great extent.

Contracts:

- Reqn. 4-9213 "Development of a solid state arsenic probe for use in pyrometallurgical processes", J. Kirchnerova and C.W. Bale, Ecole Polytechnique, Montréal. S.A. - J.M. Skeaff.

- Reqn. 6-9066 "Development of a solid state sulphur probe for use in pyrometallurgical processes (UP-M584)", J. Kirchnerova and C.W. Bale, Ecole Polytechnique, Montréal. S.A. - J.M. Skeaff.

Reports/Publication:

- J.M. Skeaff, P.R. Mainwaring and J.L. Speelman, "Thermochemical arsenide-oxide equilibria in the system Ni-As-O determined electrochemically between 438°C and 866°C"; Can Metal Quarterly 24:4:349; 1985.

- L.J. Wilson and S.A. Mikhail, "Investigation of the oxidation of niccolite by thermal analysis"; Thermochima Acta 112:197-213; 1987.

- **Project 30.86.05:** National Uranium Tailings Research Program (NUTP)
  Project leader : R. John

Objective:

The main objective of the program is to provide a scientifically credible information base which will assist government regulatory agencies and mining industry to establish long-term management strategies for uranium tailings for the protection of the public and the environment.

The program has been organized into the following major sections: Modelling, Disposal Technology and Measurement and Fundamental Understanding. The modelling activity is central to the program, but it is dependent on research into fundamental understanding of the science to develop its predictive equations. It is also dependent on the imput of measured values to calibrate and validate the models developed. Additionally, the disposal technology options must be understood to evaluate the consequences of each option and the relationship of performance to cost.

(a) Modelling

In 1986/87, the third phase of development of a probabilistic system model for predicting long-term effects of uranium tailings was completed. Subsequently, the model (called UTAP for Uranium Tailings Assessment Program) was applied to the Lacnor tailings in the Elliot Lake area (using data from a previous NUTP field program), and to the Rabbit Lake tailings in Saskatchewan (jointly with Eldorado Resources Ltd.).

(b) Disposal technology

The disposal technology section of the work is concerned with the actual physical placement of tailings after close-out. The NUTP has concentrated its efforts into technology that is or has been used in Canada. The evaluations of the technology have adopted three points of view: scientific integrity, the effectiveness in reducing contaminant concentrations and the costs. Subject areas such as liners, both natural and artificial, pyrite oxidation, consolidation, tailings covers and stability of structures have been or are being investigated.

The major effort, in this fiscal year, was placed on the preparation of a manual for uranium tailings disposal technology. It describes in a generic way disposal technologies available for Canadian uranium tailings deposits, although international experience is included.

As an addition to a major field program completed the previous year, a study of dust generation at the Gunnar tailings in Saskatchewan was undertaken.

Two research contracts will be of particular interest to the Reactive Acid Tailings Program as well. One is intended to develop a practical laboratory methodology to examine the effectiveness of alternate solid cover materials in controlling the rate of oxygen and water movement into the tailings. The second examines acid-generation from waste rock piles.

(c) Measurement and fundamental understanding

The Measurements section has two functions. The first is to provide input data for model calibration and validation. Data have been collected under a number of field programs funded by the NUTP. The second function of the Measurements section is the development of fundamental understanding of the pathways used by tailings contaminants towards mankind.

Of key importance here, is the chemistry of the source terms. Past work had concentrated on radium geochemistry. This year emphasis was given to thorium, arsenic, and nickel. Of particular interest for the Elliot Lake region is the oxidation of sulphur-bearing minerals, including the role played by bacteria.

The NUTP sees sedimentation as being a major sink for contaminants. Therefore, a series of contracts have been awarded to study various aspects of the sedimentation process. This year, arsenic and nickel behaviour in sediments was studied further.

UTAP was compared with results from Atomic Energy of Canada Ltd.'s, SYVAC computer code, and with other probabilistic codes in a Nuclear Energy Agency - sponsored exercise. The physical and chemical models used in UTAP were subjected to a peer review by a group of experts. These added to the confidence in UTAP's predictive capability already gained through other quality assurance procedures.

Contract reports:

- SSC OSQ85-00130 "Monitoring of layered uranium tailings - Phase II", Knight & Piesold Limited. S.A. - D.G. Feasby.

- SSC OSQ85-00181 "Geochemical behaviour of various non-radionuclide contaminants in uranium mill tailings", Beak Consultants Limited. S.A. H.F. Steger.

- SSC OSQ85-00182 "Probabilistic model developments for the assessment of the long-term effects of uranium mill tailings in Canada Phase III", SENES Consultants Limited. S.A. - R.W. Holmes.

- SSC OSQ85-00207 "Demonstration of the probabilistic system model for the assessment of the long-term effects of arsenic/nickel rich uranium mill tailings deposits in Canada", Beak Consultants Limited. S.A. - R.W. Holmes.

- SSC OSQ85-00213 "The fate of radium in uranium leaching and its consequent dissolution mechanisms", Chemex Labs Limited. S.A. - H.F. Steger.

- SSC OSQ85-00218 "Consolidation of uranium mill tailings", Geocon Inc. S.A. - D.G. Feasby.

- SSC OSQ85-00219 "Study of the solubility of radium-226 in sulfate media", Chemex Labs Limited. S.A. - H.F. Steger.

- SSC OSQ85-00225 "Risk assessment for Canadian uranium mill tailings - Phase II", SENES Consultants Limited. S.A. - R.W. Holmes.

- SSC OSQ85-00226 "Review of the technology of earth covers for inactive uranium mill tailings in Canada", Steffan, Robertson and Kirsten (B.C.) Inc. S.A. - D.G. Feasby.

- SSC OSQ85-00227 "Stability of structures for uranium mill tailings retention", Steffan, Robertson and Kirsten (B.C.) Inc. S.A. - D.G. Feasby.

- SSC OSQ85-00237 "Estimation of the limits for acid generation by bacteria assisted oxidation in uranium mill tailings", SENES Consultants Limited. S.A. - H.F. Steger.

- SSC OSQ85-00247 "Investigation of bacteria-catalyzed reactions occurring in uranium mill tailings at low oxygen levels", Dobrocky Seatech Limited. S.A. - H.F. Steger.

- SSC OSQ85-00289 "Study of radium-226 co-precipitates in uranium mill tailings by secondary ion-mass spectrometry", Atlantic Nuclear Services Limited. S.A. - H.F. Steger.

- SSC OSQ85-00293 "Comparison of the National Uranium Tailings Program's probabilistic model (UTAP) with the Syvac Computer code of Atomic Energy of Canada Limited", Atomic Energy of Canada Limited (WNRE). S.A. - R.W. Holmes.

- SSC OSQ85-00299 "Alternative uranium ore processing technology", SENES Consultants Limited. S.A. - D.G. Feasby.

- SSC OSQ85-00306 "Study of radiobarites in uranium mill tailings", Beak Consultants Limited. S.A. - H.F. Steger.

- SSC OSQ85-00319 "Analysis of thorium-230 in leachates from bacteria - catalysed oxidation", Dobrocky Seatech Ltd. S.A. - H.F. Steger

- SSC OSQ85-00403 "Speciation of arsenic and nickel in sediments in Moira Lake", AECL/CRNL. S.A. - H.F. Steger.

Contracts:

- SSC 23317-6-1730/01-SQ "Manual for uranium mill waste disposal technology in Canada", Steffen, Robertson & Kirsten (B.C.) Inc. S.A. - D.G. Feasby.

- SSC 23317-6-1732/01-SQ "Collection of dust samples at Gunnar uranium tailings site, Saskatchewan", Eldorado Resources Ltd. S.A. - D.G. Feasby.

- SSC 23317-6-1737/01-SQ "Development of laboratory methodology for evaluating effectiveness of engineered covers for reactive tailings", Centre de Recherche Noranda. S.A. - R.D. John.

- SSC 23317-6-1738/01-SQ "The management of acid-generating waste rock at Canadian mines (UP-N6-019)", Nolan, Davis and Associates (NS) Ltd. S.A. - R.D. John.

- SSC 23317-6-1723/01-SQ "Study of the geochemistry of thorium in uranium mill tailings", Melis Consulting Engineers Ltd. S.A. - H.F. Steger/C.W. Smith.

- SSC 23317-6-1724/01-SQ "Radionuclide movement within the biosphere and the potential dose to man from pathways through plants and animals", Monenco Consultants Limited. S.A. - H.F. Steger/C.W. Smith.

- SSC 23317-6-1725/02-SQ "The potential of genetic and adaptive changes to bacteria in uranium mill tailings", Beak Consultants Ltd. S.A. - H.F. Steger/C.W. Smith.

- SSC 23317-6-1727/01-SQ "Study on the state of nickel and arsenic in uranium mill tailings", Melis Consulting Engineers Ltd. S.A. - H.F. Steger.

- SSC 23317-6-1734/01-OTT "Technical edit french analytical manual", Eldorado Nuclear Limited. S.A. - R.D. John.

- SSC 23317-6-1736/01-SQ "Kinetics of arsenic and nickel in sediments in Moira Lake", Atomic Energy of Canada Ltd. - Research Company. S.A. - C.W. Smith/H.F. Steger.

- SSC 23317-6-1728/01-SQ "Probabilistic system model development and application to a real site - Phase IV", SENES Consultants Ltd. S.A. - R.W. Holmes.

- SSC 23317-6-1729/01-SQ "Application of the National Uranium Tailings Program probabilistic system moded (UTAP) to the Rabbit Lake Uranium tailings site", Beak Consultants. S.A. - R.W. Holmes.

- SSC 23317-6-1731/01-SQ "Comparison of the National Uranium Tailings Program's probabilistic code UTAP (Phase III) with Atomic Energy of Canada Limited's SYVAC-3 computer code", Atomic Energy of Canada Ltd. - Research Company. S.A. - R.W. Holmes.

- SSC 23317-6-1735/01-GR "Peer review of the National Uranium Tailings Program's (NUTP) probabilistic system model", Atomic Energy of Canada Ltd. - Research Company. S.A. - R.W. Holmes.

- **Project 30.86.06: Secretariat, Reactive Tailings Study (RATS)**
  Project leader : E.G. Joe

Objective:

To provide a comprehensive scientific, technical and economical basis for the mining industry and governmental agencies to predict, with confidence, the long-term management requirements for reactive tailings and waste rock.

To establish techniques that will enable the operation and abandonment of acid-generating tailings and waste rock disposal areas in a predictable, affordable, timely and environmentally acceptable manner.

There are 8 major research areas in the program:

- State-of-the-Art
- New Disposal Methods
- Evaluation of National Uranium Tailings Program Information (NUTP)
- Research Procedures
- Predictive Techniques
- Oxygen Barriers
- Passive Techniques
- Waste Rock Rehabilitation

MSL is active in most of these research areas.

Organization:

In June 1986, a Steering Committee for the RATS program was formed by CANMET, MSL. The Committee is chaired by Dr. F. Frantisak, Vice-President Environment, Noranda Inc. E.G. Joe is the executive secretary. The members represent industry, Federal and Provincial Governments:

Industry:	Cominco, Falconbridge, Hudson Bay Mining and Smelting, INCO, Noranda, Sherritt Gordon Mines
Provinces:	B.C., Manitoba, Ontario, Quebec, New Brunswick
Federal:	CANMET, Environment Canada

The Steering Committee provides overall direction to the program and will meet at least twice annually. The executive committee will meet more frequently as required.

A Technical Working Group under the chairmanship of C. Ferguson, Director-Environmental Affairs, INCO Ltd. was also formed and charged with the responsibility to develop technical objectives and scope and to monitor individual projects; basically to manage all technical aspects of the program. All above organizations are represented on the Technical Working Group.

Program cost and schedule:

It is estimated that the necessary technical effort to achieve the program objectives will require at least five years and cost in excess of $5,000,000.

It is foreseen that the costs will be shared equally among the mining sector, the provincial governments and the federal government.

Commitments to participate financially and with other resources have been received from CANMET and several corporations at $2 million. However, the program is still short of resources and requires additional funding from all parties involved at approximately $3 million over the next 5 years.

Fluidized-Bed Combustion

- Project 50.62.01: Bubbling Bed Performance Parameters
  Project leader : F.D. Friedrich (ERL)

Objective:

To delineate parameters influencing the performance of Canadian coals and other solid fuels, and pitch residues from oil sands/heavy oil upgrading; to characterize the sulphur sorbent performance of Canadian limestones, and study the effects of fuel ash on sorbent performance; to advance the level of knowledge concerning fundamental mechanisms of FBC.

(a) Characterization of the sulphur sorbent performance of Canadian limestones

MSL's portion of this project, which was to characterize Canadian limestones as SO_2 sorbents, has been essentially completed this year. However, the bench-scale fluidized-bed reactor that was developed to evaluate limestones for FBC will be maintained to service future industry and power companies requirements. A series of tests were conducted on various sizes of three New Brunswick limestones in order to determine the optimum sorbent for the Chatham circulating fluidized bed combustor. Results of this work were reported in "Evaluation of New Brunswick limestone as SO_2 sorbents in fluidized bed combustors".

The past five years' work on the evaluation of SO_2 sorbents has been compiled as a CANMET Report, "Evaluation of SO_2 sorbent utilization in fluidized beds", which is now in the editorial stage.

(b) Characterization of reaction products from fluidized bed combustion

Coal, limestone, and ashes from the bed, cyclone and baghouse of an atmospheric fluidized bed unit were studied. Thermogravimetry and

concurrent differential thermal analysis were used in developing a method for monitoring the efficiency of the combustor. Unreacted coal and limestone were determined quantitatively and thermal analysis techniques were found dependable, convenient and superior to chemical analytical methods, particularly in differentiating between the combustion of carbon and the decomposition of calcium carbonate in the samples.

Reports:

- C.A. Hamer, "Evaluation of New Brunswick limestone as SO_2 sorbents in fluidized bed combustors"; Division Report MSL 86-108 (TR).

- S.A. Mikhail, "Potential use of thermal analysis in monitoring fluid bed combustors"; Division Report MSL 86-89 (OP&J).

- **Project 50.62.02:** Circulating Bed Combustion Systems
  Project leader : F.D. Friedrich (ERL)

Objective:

To erect and commission a circulating FBC pilot plant at CCRL, CANMET; to identify and accelerate potential applications for circulating FBC in industry and power generation.

(a) Vanadium and sulphur capture from byproduct coke

MSL's project element is to investigate emissions of SO_2 and heavy metals, i.e., Ni and V; their capture with limestone, and corrosive effects from the combustion of tar sands byproduct coke in a circulating fluidized bed. A pilot-scale circulating fluid bed unit was designed and built in MSL. Two major combustion test series were conducted this year; the first with Syncrude coke and limestone and the second with Minto coal and three New Brunswick limestones. Approximately 30 one day runs were done with each fuel. Metal corrosion probes from each series were examined by the PMRL Corrosion Section. Preliminary results show that although there was fairly severe corrosion, there was no evidence that vanadium in the Syncrude coke contributed to the metallic corrosion.

Material balances account for 93% of the vanadium and 93% of the nickel in the various ash streams, that is, the bed, boiler, and baghouse. Over 90% of the sulphur was captured by the limestone at a Ca/S = 2.0. The chemical composition of the three ash streams is practically identical to the results from combustion trials with this material at the Ahlstrom CFBC unit in Finland.

The trials with Minto coal were conducted as a control for the corrosion probes and also to determine the best limestone for N.B. Power to use in the Chatham CFBC. Some test results were erratic and must await chemical

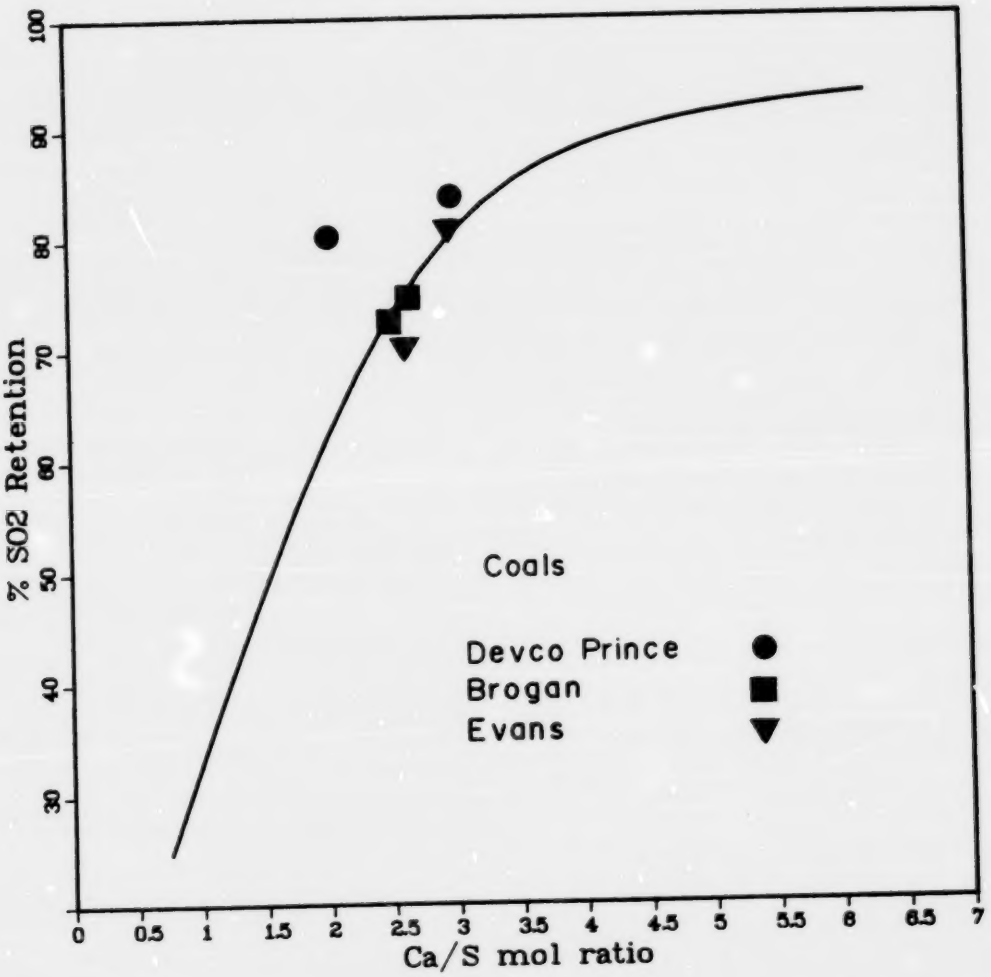

Fig. 10. Model prediction curve for sulphur retention, based on fluidized bed reactor characterization and actual performance data for the combustion of three coals, on Havelock, N.B. limestone in the Summerside FBC unit.

analysis to determine the true sulphur capture. Recommendations were made to N.B. Power to use Elmtree Limestone as there was little difference in the performance of the two Elmtree limestones and the Havelock limestone. A report describing all of this work on the pilot CFBC is being written.

MINERAL DEVELOPMENT AGREEMENT

Nova Scotia

The Research and Technology Sector of the Canada-Nova Scotia MDA managed six contracts costing $793K during FY 1986/87. The contract studying fly ash and furnace slag in concrete is showing that fly ash improve the quality of concrete. A contract on sampling methods and processing requirements for evaluating offshore gold resources has recommended two ocean bottom mounted drills and has indicated that the gold is generally in the fine minus 74 micron size. A contract evaluation processing requirements on three auriferous gold deposits has shown the viability of ore sorting separation, and excellent gold recovery by convention gravity and flotation techniques. Processing and feasibility studies conducted on celestite ore from two deposits have produced high grade strontium sulphate concentrates, followed by cost effective conversion to carbonate and metal. Processing investigations on the Pinebrook barite deposit have shown the ore can be readily upgraded to drilling mud specificaitons by gravity techniques.

Similarly, encouraging results are being developed in the processing of magnetic ores to produce finely ground magnetite for heavy media separation applications.

Newfoundland

The four Non-Mining related projects under the Mining and Minerals Technology Program for which CANMET - MSL was responsible cost $600K during FY 1986/87. The contract on Selection of Mineral Deposits in Newfoundland Suitable for Research permitted to select two deposits: Labrador City - quartzite and Tulks Hill - zinc/lead/copper. As follow up to this selection the Laborador City - quartzite project was contracted out. Two deposits underwent core drilling/sampling: the "Fermont Highway" and the "2907 Hill". The grade in both exceeds 97.5% SiO_2 with Fe lower than 0.24% and Al under 0.48%. At least one of these deposits has a potential for industrial development.

The Evaluation of Point Leamington Deposit progressed. Four holes totalling 609.6 metres were drilled and core samples sent to Noranda Research where preliminary grinding and flotation tests gave promising results especially for Zn recovery.

The Evaluation for Potential Alkali - Reactivity of Concrete Aggregates was studied. Samples of aggregate material from existing and potential sources are being collected and classified. Petrographic studies were advanced. Preparations for pouring concrete and measurements of its properties was done. As concerns the Iron Ore project - evaluation of binders - first part - was completed. Two binders Allchem 8C26 and peat moss gave promising results. Further studies using these substances are planned. The project on increasing the iron ore recovery started with sampling and mineralogical

analyses of Fe and Mn bearing phases. Twenty-five tonnes of sample was prepared and shipped for bench scale tests.

New Brunswick

The Canada/New Brunswick MDA managed seven contracts during the fiscal year 1986/87. As the province's complex sulphide orebodies have relatively poor metal recoveries and present technology is pollution-prone, a program was initiated to develop new technology to deal with these concerns, using the ferric chloride leach process. A further project is concerned with the province's very large but low-grade manganese deposits. A feasibility study is investigating the aspects required to extract a marketable product from the deposit. The evaluation of aggregates for alkali reactivity is the topic of another project. It is concerned with deterioration of concrete structures caused by alkali reactivity. In connection with the potash industry, image analysis techniques are being used to optimize processing circuits and the use of waste salt as backfill is being studied. Two projects to be initiated in 1987 are (i) the optimization of mining technology for the Brunswick Mining and Smelting No. 12 mine and (ii) the creation of a mine services software program. The program will integrate data from surveying, planning, production, etc. with the goal of providing greater productivity and a better health and safety environment. New projects continue to be sought for execution under the MDA.

Saskatchewan

The Science and Technology Sector (Sector B) of the Saskatchewan - Canada MDA managed six contracts during the fiscal year 1986/87. A shared cost contract (with SPPA) was signed in February 1987 to conduct research on microseismic technology in potash mines. Regional subsidence is also a concern in potash mines and a one year contract was initiated to develop predictive modelling. Another shared cost program (with Cominco) was started during the year to study dense media separation as an applicable beneficiation technology for potash. A parallel program on the use of dry magnetic separation was started (with Central Canada Potash). Both beneficiation studies are to last two years. A three year study on electrostatic beneficiation of potassium chloride (sylvite) from sodium chloride (halite) continued. The results are encouraging enough to permit research to continue into the third year. A shared cost contract managed by Potash Corporation of Saskatchewan aimed at improving the quality of exported potash products was started during the year. Test work will be completed in June 1987 and recommendations for industry wide action will be made by early 1988. Total contract expenditure was $252K including $101K by the potash industry.

Manitoba

Under the Research and Technology Sector of the Canada/Manitoba Mineral Development Agreement, CANMET's Mineral Sciences Laboratories are responsible for delivery of the federally funded Processing Technology

projects. During FY 1986/87 there were 11 active federally funded processing projects which involved the management of 16 separate contracts. Expenditures for this period amounted to $546.9K.

The final report on the testwork and flowsheet development to verify the technical feasibility of the GCM process for application to HBM&S copper concentrates has been completed and an economic evaluation is underway. Under a project on recovery of gold/silver from zinc pressure leach sulphide residues, a final report has been received on three hydrometallurgical alternatives (thiourea, chloride and cyanide leach). Further testwork is planned to determine why thiourea or chloride extraction is not technically feasible. Production of ZPL residues for larger scale testing was completed under contract and testwork on a pyrometallurgical alternative was initiated.

A contract on recovery of metals from oxide tailings residues indicated encouraging results, however, further testwork is required before a preliminary economic assessment could be made. A project on pyrrhotite rejection is progressing on schedule and has shown that emphasis on resolving the smelter energy balance due to high levels of pyrrhotite is required. A contract involving applied mineralogy for the improvement of metal recoveries from the Trout Lake deposit is successfully nearing completion. Two cost-shared projects were initiated with Sherritt Gordon's Ruttan mine, one on the application of column flotation technology to zinc rougher and scavenger concentrates and one on flotation process control. Both projects are showing encouraging results. Work continued on a multi-phased study on the processing and economic evaluation of the Bird River Chromite deposit.

A final report on the laboratory and pilot-plant investigations has been completed and a preliminary economic assessment has identified the potential for production of stainless steel. A study on the comminution of gypsum to determine the potential benefits of fine grinding relative to calcining characteristics and water requirement in manufacture of wallboard was completed. The results showed that the amount of water used in gypsum board manufacture can be reduced using surfactants, however, this may not always be cost effective; also stucco grinding or stucco surface treatment could have potential for reducing water demand but are still unproven. Another completed study, dealing with the upgrading of feldspar at Tanco, showed that the most cost-effective and highest yield method of ensuring that specification grade feldspar is achieved is close control of the existing heavy media circuit.

PART B. GENERAL SERVICES AND OPERATIONS

CHEMICAL LABORATORY

Manager: H.F. Steger

Summary of Analytical Services

The figures tabulated below refer to the number of analyses performed by the Chemical Laboratory in support of CANMET programs in the period from 01 April, 1986 to 31 March, 1987.

Sub-Sub-Activity	Ores and Fire Assay Section	Metals and Alloys Section	Research Sections: Reference Materials	Research Sections: Special Projects	Solution Chemistry Section	Spectrochemistry Section: Optical Emission Neutron Activation	Spectrochemistry Section: XRF, Radiometry Fluorimetry	Spectrochemistry Section: Umpire Analysis	Totals
Mining									
14.39.01	28	0	0	0	0	0	0	0	28
Coal Mining and Preparation									
20.79.01	8	0	0	0	0	0	0	0	8
Mineral Processing									
30.05.01	144	0	0	0	0	0	0	0	144
30.05.99	6	0	0	0	0	0	0	0	6
30.13.02	152	0	0	0	0	4	0	0	156
30.13.04	102	193	0	0	14	0	89	0	398
30.21.01	9	0	0	0	0	0	0	0	9
30.21.02	647	0	0	36	5	0	1867	0	2555
30.29.02	0	0	0	0	0	16	0	0	16
30.29.03	0	0	0	0	0	14	0	0	14
30.37.01	0	0	0	0	40	0	0	0	40
30.45.01	16	0	0	0	923	15	0	0	954
30.52.02	470	159	0	0	6860	1010	239	0	8738
30.52.03	1432	93	0	66	3547	1912	519	0	7569
30.52.05	126	26	0	0	120	172	0	0	444
30.52.06	0	0	0	0	87	0	0	0	87
30.52.99	338	1442	0	0	423	433	917	0	3553
30.61.01	39	7	0	0	366	249	402	0	1063
30.61.99	0	502	0	0	0	0	111	620	1233
30.69.01	34	41	0	0	0	0	685	0	760
30.69.02	17	53	0	0	0	54	4	0	128
30.69.99	0	159	0	0	0	18	0	0	177
30.77.01	990	105	0	0	127	93	0	0	1315
30.77.02	408	0	0	0	0	30	0	0	438
30.86.01	166	551	0	0	1747	133	538	0	3135
30.86.02	335	0	0	0	0	0	0	0	335
30.86.03	315	454	0	0	2416	21	0	0	3206
30.86.04	12	0	0	0	30	6	0	0	48
30.86.05	0	0	0	0	2	0	2	0	4
30.86.06	0	0	0	0	0	54	0	0	54
FUELS TECHNOLOGY									
50.62.01	1	6	0	0	0	0	0	0	7
50.62.03	844	5	0	0	0	81	0	0	930
METALS & MATERIALS									
70.04.01	0	218	0	0	0	969	6	0	1193
70.04.02	0	97	0	0	0	48	0	0	145
70.04.03	0	40	0	0	0	34	0	0	74
70.04.05	0	10	0	0	0	0	0	0	10
70.04.06	0	202	0	0	0	1243	0	0	1445
70.04.07	0	20	0	0	0	425	9	0	456
70.04.08	0	420	0	0	0	1963	126	0	2509
70.04.17	0	0	0	0	0	288	27	0	315
70.18.01	0	177	0	0	0	625	0	0	810
70.18.02	0	94	0	0	0	241	0	0	335
70.27.01	0	27	0	0	0	0	0	0	27
70.27.03	0	70	0	0	0	438	0	0	508
70.27.09	0	35	0	11	0	454	0	0	500
70.27.10	0	80	0	0	0	397	0	0	477
70.54.01	0	305	0	0	44	1673	0	0	2022
70.54.02	0	12	0	0	0	97	0	0	109
70.54.04	0	154	0	0	0	100	0	0	260
70.65.01	0	40	0	0	0	97	0	0	137
70.65.02	0	0	0	0	0	33	0	0	33
70.65.03	0	53	0	0	0	0	0	0	53
70.88.01	0	6	0	0	0	20	0	0	26
70.88.02	0	56	0	0	0	0	0	0	56
70.88.04	0	0	0	0	0	35	0	0	35
70.88.05	0	0	0	0	0	18	0	0	18
70.88.06	0	321	0	0	0	795	24	0	1140
70.91.01	0	178	0	0	0	346	63	0	587
70.91.02	0	10	0	0	0	0	0	0	10
70.91.09	0	40	0	0	0	0	0	0	40
TECHNICAL SERVICES									
85.15.00	0	0	0	0	0	5	0	0	5
TOTALS	6647	6461	0	113	16751	14663	5634	620	50889

DURING THE SAME PERIOD, 0 DETERMINATIONS WERE PERFORMED FOR THE CHEMICAL LABORATORY UNDER OUTSIDE CONTRACT(S)

EXTRACTIVE METALLURGY LABORATORY

Physical Chemistry Section

Head: A.H. Webster

(a) Thermal Analysis

Sub-sub-Activity	No. of Tests
30.21	6
30.29	10
30.52	4
50.62	28
70.65	6
70.88	5
Total	59

(b) Computer Programming

Sub-sub-Activity	No. of Jobs
30.05	1
30.13	1
30.69	1
30.77	1
30.95	1
Total	5

MINERAL PROCESSING LABORATORY

Mineralogy Section

Head: P.R. Mainwaring

Summary of Mineralogical Services

Sub-sub-Activity	SEM (Jobs)	Total Probe (Jobs)	Image Analyser (Jobs)	X-ray Diffraction (Jobs)
20.79	4	1	-	20
30.05	25	27	18	155
30.13	4	4	27	239
30.21	7	0	-	8
30.29	10	1	-	34
30.37	2	0	-	1
30.45	9	6	-	11
30.52	68	47	-	127
30.61	1	2	-	-
30.69	1	4	-	-
30.77	49	30	-	567
30.86	3	5	-	186
Totals	174	127	45	1350

Lapidary, Mineral Separation and Other Services

Services	No. Completed
Polished Sections	1286
Thin Polished Sections	95
Magnetic Separations	5
Crushing and Screen Analyses	84
Heavy Liquid Separations	24
Low-Temperature Ashing	21
Synthesis of Standards	15

PROGRAM FOR INDUSTRY/LABORATORY PROJECTS (PILP)

Project No.	Project	Industry	Scientific Authority
37	Underground Biological In-Place Leaching of Uranium Ore	Denison Mines	M. Campbell
442	Development of Solid Sodium Electrolytes	Almax Ind.	T. Wheat
634	Cement-based Dry-bagged Construction Products	Target Products & Levelton Assoc.	H. Wilson
722	Wet Processing of Asbestos	Brinco Mining (Cassiar Div.)	D.M. Doyle
723	Silica Fume Shotcrete	Target Products & Hardy Assoc.	H. Wilson
870	D.C. Plasma Arc Furnace	Inco. Ltd.	J. Skeaff
938	Low Premeability Fibrous Concrete	Gemite Unique Products Inc.	M. Malhotra
969	Column Flotation Technology Development	Cominco Ltd.	G. Feasby

COST RECOVERY CONTRACTS

025230 - The preparation for IAEA of RGTh-1, radiometric reference material

025244 - Consultation on vanadium recovery from fly ash

025256 - Gallium from bayer liquor

025257 - Rare earth recovery

025259 - A mineralogical characterization of some refractory ore leach products from Denison Mines

025260 - Plasticity of brick shales

025261 - Surface area of five samples of salt

025263 - A mineralogical analysis of mill products from Rio Algom's East Kemptville Tin Mine

025264 - Identification of a "copper arsenate" from Cominco, Trail, B.C.

025266 - A mineralogical analysis of zinc products from Kutcho Creek

025267 - Preparation of electrolytic bath reference materials

025268 - Plasticity of special clay mixtures

025269 - A liberation study and mineralogical characterization of copper circuit products from Inco, Sudbury

025271 - Ceramic properties of a clay from northern Ontario

025273 - Fission track dating of 6 samples for University of Ottawa

025275 - The determination of carbon in calcium metal for Chromasco

025276 - Consultation on crud treatment process

025277 - A mineralogical investigation of the source of manganese in raw calcite from Chromasco

025279 - A mineralogical investigation of the mode of gold occurrences in Alberts Lake test products

025281 - A mineralogical investigation of Pt-Pd bearing samples from Rutledge Lake, N.W.T.

025282 - Nickel recovery at Key Lake

025283 - A mineralogical study of the Lara deposit

025287 - The preparation of lake sediment reference samples for CCIW

025288 - Meta-Probe Inc. - SEM imaging

025292 - X-ray diffraction study of two mill products

025295 - Consultative services for laboratory set-up at Coastech Research

SPECIAL PROJECT

Nonferrous Smelter Study

• Project Leader: W.J.S. Craigen

Objective:

This project is in response to a request from MPS for CANMET's technical contribution into an overall study on the economic, technical and environmental aspects of Canada's non-ferrous smelter industry. The original objectives of the Non-Ferrous Smelter Study have, for the most part, been achieved with the publication of the two EMR special reports; one on nickel and copper, and one on lead and zinc. Major emphasis in the project is now being directed towards implementation of the technology development initiatives documented in the EMR reports, and described in more detail on a site-specific basis in the CANMET Technological Profiles. At present, government assistance to facilitate initiation of the technology development projects is being obtained from the following sources: DRIE, IRDP; Federal/Provincial MDA's; Unsolicited proposals (CANMET/DSS); PILP and NSERC.

Status:

Inco and Falconbridge have submitted their first two semi-annual progress reports, on plans for smelter modernization, to the Ontario Government. Technology development projects outlined in the Inco and Falconbridge reports are consistent with the recommendations in the EMR Special Report on Nickel and Copper, and CANMET is fully supportive of the R&D initiatives, many of which are, or will be, receiving government financial support through DRIE, IRDP.

Because of the depressed state of the iron ore industry, Algoma has opted to meet the Ontario SO_2 control order by reducing production to 0.9 million tpy from 2.0 million tpy. Although technology has been developed which would allow Algoma to meet environmental emission regulations while operating at full capacity, the company cannot afford to implement the technology at this time.

Inco has submitted and received approval for their first IRDP application to DRIE for support of a demonstration plant evaluation of a new pyrrhotite (Po) rejection process. Estimated total costs are $5.2 million (1986), about $3.5 million of which is capital. Total time frame for construction and operation is estimated at 19 months, with initiation scheduled for late 1986. CANMET has provided DRIE with supportive documentation on the project, based on verification of the potential benefits. Falconbridge has three DRIE IRDP supported technology development projects underway to meet their projected targets for smelter modernization and SO_2 control. The three projects are "Increased Roast"; Converter Slag Cleaning and Pyrrhotite Rejection", and have a combined estimated cost of $15.2 million over 5 years. All projects have been assessed and approved by CANMET, and are progressing satisfactorily. The major part of the converter slag cleaning project has been successfully completed and an interim progress report issued. Time frame for completion, however, has been extended to accommodate longer term studies on refractory life and alternate sources of ferrosilicon reductant.

Negotiations between Noranda, the Quebec Government and DRIE for the financing of the acid plant at the Horne Smelter to meet SO_2 emission targets have been completed. Although there is no technology development component directly related to the acid plant, CANMET continues to act in an advisory capacity to the federal and provincial governments on overall smelter modernization.

HBMS has completed the major portion of their social/economic study for modernizing the HBMS zinc plant using the Sherritt zinc pressure leach process, which has already been tested and evaluated by HBMS, Sherritt and CANMET. A submission to DRIE for government support to implement the new technology is expected momentarily.

Cominco has confirmed the selection of the QSL process for modernization of the lead smelter at Trail. CANMET is in general agreement with this selection based on technical, economic and environmental criteria. Implementation of the new technology, with DRIE financial support, is proceeding as scheduled.

A CIL sponsored meeting with industry and government personnel to discuss the need for a sulphur products technology association and possible implementation strategies, resulted in a commitment from seven companies to support the concept. CIL will continue to play the lead role in establishing a mandate, budget, priority list and mode of operation for the organization, prior to approaching government for financial assistance.

Nova Pb has successfully completed the first trial run on 2000 tons of Noranda Horne's smelter dusts and a second trial run has been initiated to try to improve throughputs and yields. A progress report covering the first trial run has been received at CANMET. Assistance for this project is being received through the EC/EMR DRECT program.

A Cominco/UBC co-operative project on mathematical modelling of the zinc pressure leach (ZPL) process has been initiated with NSERC support, and CANMET as scientific authority. The data generated will be very pertinent to all present and future users of the ZPL process.

An unsolicited proposal for the "Treatment of Hydrometallurgical Residues" has been submitted by Cominco to CANMET for comment and consideration for shared cost funding. The proposal is aimed at improving the separation and recovery of sulphur, lead and precious metals from hydrometallurgical process (ZPL, GCM, RLE, etc.) leach residues, and would be of particular benefit to Cominco, HBMX, Kidd Creek Mines or Noranda. CANMET is evaluating possible avenues for support in 1987/88.

A meeting was held with DRIE and Tonolli Canada to discuss an IRDP application to modernize and expand the Tonolli secondary lead smelter. A meeting was also held with Tibur-Howden to discuss progress on their DRIE IRDP demonstration plant project on plasma arc smelting for the treatment of flue dusts from ferrous and nonferrous smelters. CANMET is involved as scientific consultant to DRIE on both projects.

An unsolicited proposal from McMaster University and University of Toronto on "Direct Reduction Smelting of Sulfide Ores" has been supported by CANMET on a limited basis, after considerable revision to the original proposal. The project will investigate the possibility of producing H_2S from sulphide bearing smelter slags.

The CANMET shared cost contract with Inco Sudbury on "Copper Refinery Electrolyte Control" is nearing completion. A comprehensive literature review has been completed, and an interim report has been issued outlining the results of all testwork to date. A final report is expected by April, 1987.

The CANMET shared cost contract with Inco Sudbury on "Plasma Reduction/Melting for Utility Nickel Production" is progressing satisfactorily. Completion of the construction phase is scheduled for August, 1987.

The following smelter development projects are being carried out under the Manitoba MDA:

Pyrrhotite Rejection; Inco Thompson

The project is progressing satisfactorily and on schedule. More emphasis is now being placed on resolving the smelter energy balance problems, which result from high levels of pyrrhotite rejection.

GCM Hydrocopper Process; HBMS/Bacon Donaldson

The final report on the testwork and flowsheet development to verify the technical feasibility of the GCM process for application to HBMS Copper

concentrates has been received from Bacon Donaldson, and approved for distribution by HBMS and CANMET.

Completion of the HBMS/CANMET economic evaluation report on the GCM process is expected by April 1987. Considerable time and effort is being spent on assessing the thermal energy requirements of the process, and some changes to the BDA material balance figures, particularly in the oxyhydrolysis circuit have been necessary.

Gold/Silver Recovery from ZPL Sulphide Residues; HBMS/Bacon Donaldson and Associates/Sherritt

The BDA final report on the three hydromet alternatives (thiourea, chloride and cyanide leach) has been received. Some further testwork is planned at CANMET to try to determine why the thiourea and chloride extraction techniques are not technically feasible. The production of ZPL residues for larger scale testing of gold/silver recovery alternatives has been successfully completed by Sherritt and a final report has been issued and approved by HBMS and CANMET. Testwork on the pyrometallurgical alternative for gold/silver recovery is continuing at CANMET on a larger scale to improve the accuracy of the material balances. The comparative economic evaluation of the technically feasible alternatives is not expected to be completed until June 1987.

Gold/Silver Recovery from ZPL Oxide Residues; HBMS/Sherritt

A work statement has been issued and approved and work on this project is expected to be initiated early in 1987/88 fiscal year.

Metal Recovery from Oxide Tailings Residue; HBMS/Sherritt

Two detailed progress reports under Phase I of this study have been issued by Sherritt. Results are encouraging, however, more testwork is required before a preliminary economic assessment can be attempted. Completion of Phase I, including the preliminary economic evaluation is scheduled for April 1987. However, initiation of Phase II (if justified) may be delayed to fiscal year 88/89 due to MDA budget constraints.

During 1986/87 CANMET hs continued to be involved in a technical advisory capacity to Enhanced Recovery Systems (ERS) and to RPC on the operation and evaluation of the SRL process pilot plant at Chatham, N.B. The plant operated successfully on a continuous integrated basis for about two months during the summer of 1986, and evaluation of the processes technical and economic viability, based on the pilot-plant operation, is now nearly complete. A final report, including an engineering and economic evaluation by an outside consultant is scheduled for completion by the fall of 1987.

Contracts

- Reqn. 5-9030 "To develop S reducing mineral beneficiation techniques and perform S emission tests at Inco Smelter, Thompson, Man.", Inco Ltd. S.A. - W. Craigen.

- Reqn. 5-9129 "Gold-silver recovery from zinc pressure leach residues Phase I", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W. Craigen.

- Reqn. 5-9220 "Metal recovery oxide residues", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W. Craigen.

- Reqn. 5-9264 "Gold-silver recovery from zinc pressure leach residues Phase II", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W. Craigen.

- Reqn. 6-9191 "Gold-silver recovery from zinc pressure leach residues Phase III", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W. Craigen.

PART C. REPRESENTATION ON TECHNICAL COMMITTEES

INTERNATIONAL

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

Barkley, D.J.
- Member, CAC/ISO/TC 26/SC 1, Copper and Copper Alloys;
- Member CAC/ISO/TC 17/SC 1, Analysis of Steel and Cast Iron.

Chen, T.T.
- Member, CAC/ISO/TC 175, Fluorspar.

Graham, J.A.
- Member, CAC/ISO/TC 183, Copper, Lead and Zinc Ores and Concentrates.

Hole, J.C.
- Member, CAC/ISO/TC 102, Iron Ores;
- Chairman, CAC/ISO/TC 102/SC 2, Iron Ores.

Mainwaring, P.R.
- Member, Joint CAC/ISO/TC 146/147/SC 3, WG1, Detection Asbestos Fibre in Air.

Malhotra, V.M.
- Chairman, CAC/ISO/TC 71, Concrete (SC 1 and SC 3).

Smith, C.W.
- Member, CAC/ISO/REMCO, Committee on Reference Materials.

Steger, H.F.
- Chairman, CAC/ISO/REMCO, Reference Materials.

Sutarno, R.
- Member, CAC/ISO/TC 102, Iron Ore;
- Chairman, CAC/ISO/TC 102/SC 1, Sampling Subcommittee;
- Convener, ISO/TC 102/SC 2/WG 12, Chemical Analysis Subcommittee, Working Group on Evaluation of Statistical Data;
- Canadian Representative to Study Group on Reference Materials - Iron Ores, CAC/ISO/TC 102/SC 2;
- Member, CAC/ISO/TC 69, Application of Statistical Methods;
- Chairman, CAC/ISO/TC 69/SC 6, Measurement Methods and Results;
- Canadian Representative to ISO/TC 69/SC 6/WG 1, Revision of ISO 5725;
- Convener, ISO/TC 69/SC 6/WG 4, Joint Working Group between ISO/TC 69 and ISO/REMCO on Statistical Aspects of Reference Materials;
- Member, CAC/ISO/REMCO, Reference Materials;
- Member, CAC/ISO/TC 183, Copper, Lead and Zinc Ores and Concentrates;
- Convener, ISO/TC 183/WG 10, Statistical Evaluation of Test Programs.

Wilson, J.M.D.
- Member, CAC/ISO/TC 24, Sieves, Sieving and Other Sizing Methods;
- Member, CAC/ISO/TC 102, Iron Ores (SC 3 and SC 5).

INTERNATIONAL MINERALOGICAL ASSOCIATION

Cabri, L.J.
- Canadian Representative, Commission of Ore Microscopy;
- Rapporteur, Analytical Methods Subcommittee, Commission of Applied Mineralogy.

Chen, T.T.
- Member, Committee on Sulphosalts.

Petruk, W.
- Member, Applied Mineralogy Committee.

INTERNATIONAL COMMITTEE ON APPLIED MINERALOGY IN THE MINERAL INDUSTRY

Petruk, W.
- Canadian Representative;
- Liaison Representative.

INTERNATIONAL ATOMIC ENERGY AGENCY

Campbell, M.C.
- Member, Consultants Group on Uranium Extraction.

Dalton, J.L.
- Consultant, Analytical Techniques in Uranium Exploitation, Development and Ore Processing.

INTERNATIONAL ENERGY AGENCY

Ahmed, S.M.
- Canadian Technical Contact Person to the I.E.A. for Task VI (Photocatatylic Water Electrolysis) for the Program of Research and Development and Production of Hydrogen from Water.

MISCELLANEOUS

Cabri, L.J.
- Editor, 3rd Special Platinum Issue Journal of Economic Geology.

Carette, G.G.
- Member, 2nd International Conference on the Use of Fly Ash, Slag and Silica Fume, Madrid, 1986.

Dutrizac, J.E.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing, Co., Amsterdam.

Holmes, R.W.
- Member, Nuclear Energy Agency, Probabilistic Systems Assessment Code Users Group.

MacKinnon, D.J.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam.

McCready, R.G.L.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam.

Malhotra, V.M.
- Chairman, 2nd International Conference on the Use of Fly Ash, Slag, and Silica Fume, Madrid, 1986;
- Member, Committee on NDT of Concrete.

Mirkovich, V.V.
- Director, International Thermal Conductivity Conference;
- Member, Editorial Board, International Journal of Thermophysics, Plenum Press, N.Y.

Ritcey, G.M.
- Member, International Solvent Extraction Technology Committee;
- Editor, International Journal of Hydrometallurgy, Elsevier Pub. Co., Amsterdam;
- Member, Editorial Board, Journal of Separation Process Technology, C. Lildwell Press, England;
- Member, Editorial Board, "Science and Technology of Tributyl Phosphate", C.R.C. Press, Pub.;
- Member, Editorial Board "Extractive and Process Metallurgy", Gorden & Branch, Pub.;
- Member, International Conference on Separation Science and Technology - International Committee;
- Chairman, International Conference on Separation Science and Technology, Second Conference.

Sirois, L.L.
- Member, International Scientific Committee of the International Mineral Processing Congress;
- Member, 10th International Coal Preparation Congress, Organizing Committee.

Soles, J.A.
- Member, Process Mineralogy Committee, AIME;
- Member, Organizing Committee, 7th International Conference on Alkali Reactivity;
- Member, Subcommittee on Aggregate/Concrete Testing & Standards, Canadian Standards Association;

Stefanski, M.J.
- Member, 10th International Coal Preparation Congress, Technical Program Committee.

Townsend, M.G.
- Consultant to International Group of Experts on Methodology and Monitoring of Radon, Thoron and their Daughters, Nuclear Energy Agency, Organization for Economic Cooperation and Development;
- Professeur Associé at CENG, Grenoble, France.

Wilson, H.S.
- Secretary, Treasurer, Member of Organizing Committee, 2nd International Conference on the Use of Fly Ash, Slag, and Silica Fume, Madrid, 1986.

CANADA

FEDERAL

Andrews, P.R.A., Doyle, D., Lamothe, J.M., Soles, J.A., Wang, S.S.B., Wilson, H.S.,
- Members, Interbranch Liaison, Industrial Minerals (ILIM).

Bedard, P.
- Member, MSL-EDP Committee.

Bell, D.H.
- Co-chairman, Technical Subcommittee for Mining and Mineral Technology, CANADA/NEWFOUNDLAND Mineral Development Agreement.

Campbell, M.C.
- Chairman, BIOMINET;
- Chairman, MSL-EDP Committee;
- Member, CANMET EDP Acquisitions Committee;
- Member, Uranium Resource Appraisal Group;
- Member, Biotechnology Co-ordinating Group.

Collings, R.K.
- Chairman, Interbranch Liaison, Industrial Mineral (ILIM).

Horton, R.E., Lalonde, C.
- Members, EMR Committee on Occupational Health and Safety.

John, R.D.
- Member, Advisory Committee, Second International Conference on Radioactive Waste Management.

McCready, R.G.L.
- Secretary, BIOMINET.

Pilgrim, R.F.
- Member, MSL-EDP Committee.

Smith, C.W.
- Member, MSL-EDP Advisory Committee.

Stefanski, M.
- Co-chairman, Technical Subcommittee for Mining and Mineral Technology, CANADA/ NEWFOUNDLAND Mineral Development Agreement.

Steger, H.F.
- Member, Interdepartmental Committee on Standards Policy.

Sutarno, R.
- Member, MSL-EDP Committee;
- Member, CANMET EDP Acquisitions Committee;
- MSL Representative to CANMET CAD Committee.

DEPARTMENT OF REGIONAL INDUSTRIAL EXPANSION

Craigen, W.J.S.
- Member, Technical Advisory Committee for the Canada - New Brunswick Sulphation Roast Leach Pilot Plant;
- Member Board of Directors for Enhanced Recovery Systems (ERS);
- Member, Technical Advisory Committee for Northern Smelters Modernization.

CANADIAN GENERAL STANDARDS BOARD

Douglas, E.
- Member, Committee GP-34, Asbestos-Cement Products.

UNIVERSITY OF BRITISH COLUMBIA
THE CENTRE FOR METALLURGICAL PROCESS DEVELOPMENT

Campbell, M.C.
- Member, Technical Advisory Board.

ENVIRONMENT CANADA

Joe, E.G.
- Member, Gold Processors Working Group.

NATIONAL SCIENCES AND ENGINEERING RESEARCH COUNCIL

Bell, D.H.
- Scientific Secretary, Grant Selection Committee, Chemical and Metallurgical Engineering.

Dutrizac, J.E.
- Member, Grant Selection Committee, Chemical and Metallurgical Engineering.

Townsend, M.G.
- Member, Committee on Technology for Silicon Integrated Circuits.

MISCELLANEOUS

CANADIAN CERAMIC SOCIETY

Ahmad, A.
- Member, Electronics and Basic Science Division;
- Chairman, Electronics and Basic Science Division, Technical Sessions;
- Judge, Ceramographic Competition.

Canaday, J.D.
- Associate Editor, Journal of Canadian Ceramic Society.

Kuriakose, A.K.
- Chairman, Ceramographic Committee;
- Associate Editor, Journal of CCS;
- Director, C.C.S.;
- Session Chairman, CCS Annual Meeting, Electronics and Basic Sciences Division.

Wheat, T.A.
- Director, Electronics Basic Science Division;
- Chairman, Publications Committee.

CANADIAN COMMITTEE ON ANALYTICAL CHEMISTRY RELATED TO CANADA'S NUCLEAR INDUSTRY

Dalton, J.L.
- Member, Organizing Committee for 4th Workshop (May 1988).

CANADIAN INSTITUTE OF MINING AND METALLURGY

Cabri, L.J.
- Representative, Special Volumes.

Collings, R.K.
- Member, Special Volumes Committee.

Doyle, D.
- Secretary, Canadian Mineral Processors Division;

Dutrizac, J.E.
- Co-chairman, 1986 International Symposium on Iron Control in Hydrometallurgy;
- Member, Historical Metallurgical Committee;
- Member, Hydrometallurgy Section Executive.

Laguitton, D.
- Member, Computer Applications and Process Control Committee.

Lalonde, C.R.
- Building Representative, 555 Booth St.;

MacKinnon, D.J.
- Publicity Chairman, 1986 International Symposium on Iron Control in Hydrometallurgy.

Mainwaring, P.R.
- Chairman, Mineral Sciences and Engineering Section, Metallurgical Society.

Ritcey, G.M.
- Member, Hydrometallurgy Section Executive.

Skeaff, J.M.
- Publicity Chairman, 1988 CIM Conference of Metallurgists.

CANADIAN MINERAL PROCESSORS CONFERENCE

Joe, E.G.
- Treasurer.

Doyle, D.
- Secretary.

CANADIAN NATIONAL COMMITTEE FOR THE INTERNATIONAL UNION OF CRYSTALLOGRAPHY

Szymanski, J.T.
- Secretary.

CANADIAN STANDARDS ASSOCIATION

Andrews, R.P.A.
- Member, Committee on Gypsum and Lime (A.82);
- Chairman, Editorial Subcommittee.

Carette, G.G.
- Member, Committee on Cement (A.5);
- Member, Committee on Cement Admixtures.

Malhotra, V.M.
- Member, Executive Committee on Aggregates and Concrete (A.23.1, A.23.2, A.24.3);
- Member, CSA Committee (A.23.1).

Soles, J.A.
- Member, Subcommittee on Cement-Aggregate Reactivity;
- Member, Committee on Cement and Aggregate.

Sutarno, R.
- Member, Committee on Applications of Statistical Methods.

CANADIAN SOCIETY OF CIVIL ENGINEERING

Malhotra, V.M.
- Member, Technical Activities Committee;
- Associate Editor, Canadian Journal of Civil Engineering.

CANADIAN URANIUM PRODUCERS'S METALLURGICAL COMMITTEE

Dalton, J.L.
- Treasurer, Analytical Subcommittee;
- Convenor, X-ray Fluorescence Analysis Course, CANMET.

CHEMICAL INSTITUTE OF CANADA

Hole, J.C.
- Chairman, Committee of Scrutineers.

Leaver, M.E.
- Member, Ottawa Section Professional Affairs Committee.

IRON ORES PROCESSORS TASK FORCE

Cameron, W.
- Chairman and Secretary.

Campbell, F.R., Doyle, D., Kuriakose, A.K., Quon, D., Stefanski, M.J., Wilson, J.M.D.
- Members.

MINERALOGICAL ASSOCIATION OF CANADA

Cabri, L.J.
- Past President;
- Chairman, Nominating Committee;
- Chairman, Past Presidents' Medal Committee.

Szymanski, J.T.
- Associate Editor, Canadian Mineralogist.

SPECTROSCOPY SOCIETY OF CANADA

Leaver, M.E.
- Publicity Chairperson, XXV Colloquium Spectroscopicum Internationale.

Wittwer, J.W.
- Director, Ottawa Valley Section.

TECHNICAL COMMITTEE ON ACID MINE DRAINAGE

McCready, R.G.L.
- Member, (Intnl. Airport Halifax).

UNITED STATES OF AMERICA

AMERICAN CONCRETE INSTITUTE

Malhotra, V.M.
- Member, Technical Activities Committee;
- Member, ACI Committee 114 on Research Needs in Concrete;
- Chairman, ACI Committee 226/Subcommittee on Silica Fume;
- Member, Malesian Research Council;
- Member, Technical Committee (214, 226, 228 and 568).

AMERICAN INSTITUTE OF MINING, METALLURGICAL AND PETROLEUM ENGINEERS

Dutrizac, J.E.
- Member, Publications Committee;
- Member, Lead, Zinc, Tin Committee.

Mainwaring, P.R.
- Member, Process Mineralogy.

Petruk, W.
- Chairman, Methodology, Process Mineralogy;
- Member, Technical Activities Committee.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

Horton, R.E.
- Member, Committee E.02, Emission Spectroscopy;
- Leader, Task Group on Line Overlap in X-ray Spectrometry.

Malhotra, V.M.
- Member, Committee C.09, Concrete;
- Chairman, C.09.02.05, Subcommittee on Non-Destructive Testing of Concrete.

Sutarno, R.
- Member, Executive Committee of E-16, Sampling and Analysis of Metal-Bearing Ores;
- Member, Working Group on Sampling.

AMERICAN CERAMIC SOCIETY

Ahmad, A.
- Member, The Basic Science Division.

Kuriakose, A.K.
- Member.

NATIONAL RESEARCH COUNCIL, U.S.A. - TRANSPORTATION RESEARCH BOARD

Malhotra, V.M.
- Chairman, Committee A2 E.03, Mechanical Properties of Concrete.

PART D. PUBLICATIONS, PAPERS, PRESENTATIONS AND REPORTS

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MSL 86-141 (IR) 30.69.03
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Andrews, P.R.A., Wong, S.S.B., Lamothe, J.M. "An evaluation of the Kipp-Kelly air table as a gravity concentration technique for industrial minerals"; September 1986.

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PART E. TECHNOLOGY EXCHANGE

PARTIAL LIST OF COMPANIES, GOVERNMENT AGENCIES, UNIVERSITIES AND RESEARCH ORGANIZATIONS WITH WHICH THE MINERAL SCIENCES LABORATORIES HAS BEEN ASSOCIATED DURING FY 1986-87

GOVERNMENT

A

Agriculture Canada

Alberta Research Council

Argentina Commercial Secretary for Mineral/Industry

Atomic Energy Commission U.S.A.

Atomic Energy Control Board

Atomic Energy of Canada Limited

Auditor General's Office

Australia Atomic Energy Commission

Australia Technical Cooperation Program

B

B.C. Ministry of Industry and Small Business

B.C. Ministry the Environment and Parks

B.C. Ministry of Energy, Mines and Petroleum Resources

C

Canada Oil and Gas Lands Administration (EMR)

Canada-Ontario Industrial Minerals Development PRG

Canada-Yukon Economic Development Agreement

Canadian Mission to the EEC

Centre de Recherches minérales (Quebec)

Chief Mines Engineer (Yukon & NWT)

Chinese National Non-Ferrous Metals Company

Commonwealth Scientific and Industial Research Organization (CSIRO) - Australia

Commissariat à l'Energie Atomique (France)

D

Department of Indian and Northern Affairs

Department of Regional Industrial Expansion

E

EC/Canada Metals and Materials Working-Group

Eldorado Nuclear Ltd.

Embassy of the People's Republic of China

Environment Canada

External Affairs Canada

F

Federal Institute for Geosciences and Natural Resources

Fisheries and Oceans Canada

H

Health and Welfare Canada

I

Italian Trade Consulate

M

Manitoba Department of Energy and Mines

Member of Parliament - Office of G. St.Germain

Mineral Policy Sector (EMR)

Ministry of International Trade and Industry - Japan

Ministry of State for Science and Technology

N

National Capital Commission

National Energy Board

National Research Council

Natural Sciences and Engineering Council of Canada

New Brunswick Deptartment of Natural Resources and Energy

Newfoundland Department of Mines and Energy

Member of Parliament - Wm.Tupper, Nepean-Carleton

Member of Parliament - D. Nickerson, Western Artic

Nova Scotia Department of Mines and Energy

O

Office of Energy Research and Development (EMR)

Ontario Ministry of Labour

Ontario Ministry of Natural Resources

Ontario Ministry of Northern Development and Mines

Ontario Ministry of the Environment

P

Panel on Energy R&D

Prime Minister's Office

Public Works Canada

Q

Quebec Ministry of Mines and Natural Resources

Quebec Ministry of Environment

R

Revenue Canada

S

Saskatchewan Department of Environment

Saskatchewan Department of Labor

Saskatchewan Department of Mineral Resources

Solicitor General Canada

T

Territorial Government (Whitehorse)

Transport Canada

U

United States Bureau of Mines

United States Department of Energy

United States - Technical Cooperation Program

V

Vice-President of Ecuador

UNIVERSITIES AND OTHER ORGANIZATIONS

A

American Concrete Institute

Annual CDN Mineral Processing Conference (18th)

Arizona University

Atlantic Coal Research Institute, College of Cape Breton

Atlantic Institute of Biotechnology

Australian Technical Cooperation Program

B

British Columbia Research

C

Canadian Institute of Mining and Metallurgy

Canadian Mineral Processors

Canadian Mining Journal

Cape Breton Development Corporation (CBDC)

Cement and Concrete Institute

Centre for Occuptional Safety and Health

Clay Brick Manufacturers Association

Collège de la Région de l'Amiante (Thetford Mines)

Conference Board of Canada

Ecole Polytechnique

G

Gypsum Association

I

Idaho National Engineering Laboratory

International Atomic Energy Agency (IAEA)

International Energy Agency

J

Japanese Government Industrial Research Institute

Japanese Metal Producing Companies

K

Korea Advanced Energy Research Institute

L

Lab Nacional De Engenharia E Tecnologgia Industri

Laurentian University

M

Manitoba Mineral Industry - 7 Companies (MDA MTG)

McGill University

McMaster University

Michigan Technological University

Mineral Exploration Research Institute

Mineral Processing Subcommittee (NACMMR)

N

National Institute for Cement and Building Materials

National Swedish Board for Technology Development

New Brunswick Electric Power Company

New Brunswick Research and Productivity Council

Northwest Territories Chamber of Mines

Nova Scotia Research Foundation

NWT Operating Mines

O

Ontario Research Foundation

Ontario Hydro

P

Portland Cement Association

Portugese National Uranium Company

Q

Quebec Metal Mining Association

Queens University

R

Reactive Acid Tailings - Technical Working Group

Resource Technology Centre

Royal Military College of Canada

S

Saskatchewan Research Council

Shanghai Research Institute of Building Science

Sir Sandford Fleming College

Société d'Aménagement de l'Outaouais

T

Technical University of Nova Scotia

The Alberta Laser Institute

Turkish Mineral Technology Institute

U

United Kingdom - Technical Cooperation Program

University of Alberta

University of British Columbia

Université Laval

University of New Brunswick

University of Ottawa

Université du Quebec à Chicoutimoi

Université du Quebec à Montreal

Univeristy of Toronto

University of Waterloo

University of Western Ontario

INDUSTRY

A

A. Chartrand, Consultant

A. Gutulov, Metallurgical Consultant

Advanced Industrial Materials Working Group

Agra Industries Limited

Air Liquide Canada Limitee

Alcan

Algoma

Almax Industries

Alsur Enterprises Limited

Altimag Consultants

Amazon Gold

American Cyanamid Limited

Amok Limited

Arctec Limited

Atlantic Nuclear Services Limited

Avalon Construction

B

BBT Geochemical Consultants

B.H. Levelton and Associates

Bailey Hoogovens Canada Inc.

Beak Consultants

Bechtel Engineers

Boliden W. P. Contech

Boojum Research

Brampton Brick Company

C

C.E.Z. Inc.

Callaham Mining Corporation

Camax Engineering

Cambrian Engineering Group Limited

Canada Brick Limited

Canada Cement Lafarge

Canadian Hunter Exploration Limited

Canadian Industries Limited (CIL)

Canterra Energy Limited

Cardinal Architects

Carter P., Consultant

Cassiar Mining Corporation

Central Canada Potash

Centre de Recherche Noranda

Chemex Labs Limited

Chemlab Inc.

Chutter D., Consultant

Cigar Lake Mining Corporation

Clifton Associates

Cluff Mining

CMS Rotordisk Inc.

Coastech Research Inc.

Column Flotation of Canada Limited

Comcor Waste Systems Limited

Cominco Limited

Consolidated Silver Standard Mines

Coopers-Lybrand

Craig E., Private Consultant

Crothers

Curragh Resources

Cyanamid Canada

D

Denison Mines

Domtar

Dobrocky Seatech Limited

Dupont Canada

Durham Mines Limited

E

Eaglebrook Environmental International

East Kemptville Tin

EBA Engineering

Ekaton Industries Inc.

Eldor Mines Limited

Elkem A/S (Norway)

Elliot Exploration Limited

Esso Resources

Extender Minerals

F

Falconbridge Limited

Fenco Engineering

Fleck Resources Limited

Fox, Jones and Associates

Fuller Construction Company

G

Garson, Garcy Enterprises

Gemite Unique Productions Inc.

Geomines Limited

Geosearch Limited

Gibraltar Mines

Global Thermoelectric Power Systems Limited

Globe and Mail - Toronto

Golder Associates

Great Central Mines

Grecian Magnesite S.A.

H

Harris N.D., Consultant

Harvey W., Consultant

Hanna Mining Company

Hatch Associates

Hawk Ridge Mineral Enterprises

Hearne Taurus

Hester K., Consultant

Hiex International Corporation

Highwood Resources

Hudson Bay Mining and Smelting Company

I

Imperial Chemical Industries (UK)

Inco

Indusmin (Div. of Falconbridge)

Industrial Ceramics Limited

International Mineral and Chemical Company

Interuranium Canada Limited

Iron Ore Company

IRDC

Issacson M., Film Maker

J

J.M. Asbestos Inc.

Jacques Whitford and Associates Limited

Johannesburg Consolidated Investment Company

K

Kaiser Aluminum

Kennedy W., Private Consultant

Khanna R. Dr., Consultant

Kidd Creek Mines

Knight and Resold

KHD Humboldt Wedag

Kilborn Engineering

Klein Dr., Mine Owner

KSK Associates

Kuntze D., Consultant

L

Lacana Mines Limited

Lake Asbestos

Lakefield Research

Lavalin

Linatex Canada

Liquid Air

Lodestone Limited

London and Scandinavian Metallurgical Company

M

Maclaren Plansearch

Madeleine Mines Limited

Maghemite Incorporated

Magstone Limited

Maltby P., Consultant

Masterloy Products Limited

McLean Hunter

Melis Consulting Engineers

MER Resources

Merrill-Lynch

Meta-Probe Inc.

Metal Recovery Industries

Metals and Mines Limited

40 Miles Placers

Mobil Oil (USA)

Monenco

Morrison Hershfield Limited

N

National Uranium Mining Company

Newmont Mines

Nodeni Consulting

Nolan, Davis and Associates

Noranda

Nordco Limited

Nova Corporation

NYCO

O

Ontario Hydro

P

Pamour Porcupine Mines

Penny Mines

Petro Canada

Pickands Mather

Pigment and Chemical Company

Pigment and Technology Inc.

Polar Resources Limited

Potash Corporation of Saskatchewan

Q

QCM

QIT - Fer et Titane Inc.

Quarm T.A., Consulting Metallurgist

R

Reichold Limited

Reiss Lime Company of Canada

Renzy Mines Limited

Resource Group

Rio Algom Limited

Robson G., Private Consultant

Roche Limited

Rockwell International

Rossing Uranium

Royal Bank of Canada

S

Seabright Resources

Seargeant Hoskins and Beckwith

Senes Consultants

Sherritt Gordon Mines Limited

Statetech

SKW

SNC Inc.

Stearns Catalytic

Steeprock Resources

Steffen, Robertson & Kirsten

Stelco Inc.

Strathcona Minerals

T

Teck Mining Company

Tenneco Limited

The Ottawa Citizen

Three Island Steel

Timminco-Chromasco

Todd Mr., Consultant

Tonolli Canada

Total Erickson Resources

Trow Limited

U

United States Reps. - Technical Cooperation Program

Utah Mines (B.C.)

W

Wabush Mining

Watkins E., Consultant

Watt Engineering Limited

Westmin Resources Limited

Weston D., Consulting Metallurgist

Wilson D., Patent Attorney

Witteck Development Inc.

Z

Zenon Environmental Inc.

PART F. PROFESSIONAL, TECHNICAL AND ADMINISTRATIVE STAFF

NAME	DEGREES	OCCUPATIONAL CATEGORY
Sirois, L.L.	B.A., B.Eng., (McGill); P.Eng.	Director MSL
Craigen, W.J.S.	B.Sc. (Queen's)	Phys. Sci.
Joe, E.G.	B.Sc. (Queen's)	Phys. Sci.
ADMINISTRATION		
Alexander, G.		Technologist
Bart, J.A.		Admin. Support
Bisson, S.		Admin. Support
de Lepper, J.		Admin. Support
Desrochers, L.R.		Admin. Support
Groulx, P.		Admin. Support
Joly, A.		Admin. Support
Lord, S.		Admin. Support
MacLeod, J.D.		Scientific Illustration
Mathurin, D.		Admin. Support
O'Reilly, J.		Admin. Support
Palmer, M.		Admin. Support
Peruzzi, M.		Admin. Support
Richer, P.		Technologist
Rochon, J.P.		Admin. Officer

NAME	DEGREES	OCCUPATIONAL CATEGORY
CHEMICAL LABORATORY		
Steger, H.F.	B.Sc., Ph.D. (McMaster)	Manager
Guest, R.J.	B.Sc. (Acadia)	Asst. Manager Operations
Atkinson, J.E.	B.A. (Queen's)	Chemist
Barkley, D.J.	B.Sc. (Carleton)	Chemist
Carson		Technologist
Charbonneau, R.		Technologist
Chenier, M.		Technologist
Churchill, T.R.	B.Sc. (Western Ontario)	Chemist
Cloutier, J.C.		Technologist
Craig, R.R.	B.Sc. (Glasgow)	Chemist
Curley, D.L.	B.Sc. (Carleton)	Chemist
Cyfracki, E.		Technologist
Dalton, J.L.	B.Sc. (Manitoba); M.Eng. (Carleton)	Chemist
Desgagné M.	B.Sc. (Laval)	Chemist
Desjardins, L.		Technologist
Donaldson, E.M.	B.Sc. (Manitoba)	Res. Sci.
Fortin, R.A.		Technologist
Graham, J.A.	B.Sc. (Carleton)	Chemist
Guibord, M.P.		Admin. Support
Guillas, R.J.		Technologist
Hole, J.C.	B.A. (Toronto)	Chemist
Horton, R.E.	B.Sc. (Carleton)	Chemist

NAME	DEGREES	OCCUPATIONAL CATEGORY
Hunt, G.A.	B.Sc. (Carleton)	Chemist
Josling, C.A.		Technologist
Kobus, R.S.		Technologist
Lalande, J.L.		Lab. Support
Lalonde, C.R.		Technologist
Leaver, M.E.	B.Sc. (Queen's)	Chemist
MacEachern, E.H.	B.Sc. (Mount Allison)	Chemist
McIntosh D.G.		Tech. Support
McCorkell, R.H.	M.Sc, Ph.D. (Manitoba)	Chemist
McCulloch, L.		Technologist
Moloughney, P.		Technologist
Nelson, G.L.		Technologist
Palombo, D.P.		Technologist
Provencher, R.	B.Sc., M.Sc., Ph.D. (Sherbrooke)	Res.Sci.
Pugliese, R.J.		Technologist
Richardson, G.		Technologist
Sawchyn, M.N.		Technologist
Sheldrick, D.		Technologist
Smith, C.W.	M.Sc., Ph.D. (Queen's)	Res. Sci.
Townsend, M.G.	B.Sc., Ph.D. (Southhampton)	Res.Sci.
Tremblay, R.J.J.		Technologist
Varette, D.M.		Admin. Support
Westra, P.		Tech. Support
Wittwer, J.W.	B.Sc. (Carleton)	Chemist

NAME	DEGREES	OCCUPATIONAL CATEGORY
EXTRACTIVE METALLURGY LABORATORY		
Campbell, M.C.	B.Sc. (St. Francis Xavier) B.Eng. (N.S.T.C.), D.I.C., M.Sc. (London); P.Eng.	Manager
Ahmed, S.M.	B.Sc., M.Sc. Ph.D. (Saskatchewan)	Res. Sci.
Bedard, P.L.		Technologist
Bell, D.H.	B.A.Sc. (Toronto); Ph.D. (London); D.I.C. (Imperial College)	Phys. Sci.
Bowman, W.S.	B.Sc., (Carleton)	Technologist
Brannen, J.M.		Technologist
Carter, L.E.		Technologist
Chalykoff, C.	B.Sc., (Carleton)	Technologist
Davidson, G.R.	B.Sc., (Carleton)	Technologist
Deschênes, G.	B.Sc., M.Sc. (Laval)	Phys. Sci.
Dinardo, O.	B.Sc. (Carleton)	Phys. Sci.
Dutrizac, J.E.	M.A.Sc., Ph.D. (Toronto)	Res. Sci.
Gould, W.D.	B.Sc. (Manitoba); M.Sc. Ph.D. (Alberta)	Res. Sci.
Hamer, C.	B.E. (N.S.T.C.), M.Sc. (Queen's); P.Eng.	Res. Sci.
Haque, K.E.	M.Sc., Ph.D. (Ottawa)	Res. Sci.
Hardy, D.J.		Technologist
Jasmin, D.		Admin. Support
Joly, M.		Tech. Support
Kearns, J.B.		Technologist

NAME	DEGREES	OCCUPATIONAL CATEGORY
La Forest, D.		Technologist
Lavallée, L.		Admin. Support
Leduc, J.	B.Sc. (Université de Montréal); M.Sc., Ph.D. (McGill)	Res. Sci.
Liang, D.	B.Sc., M.Sc. (Queen's)	P.Eng.
Lucas, B.H.	B.Sc. (Queen's); P.Eng.	Res. Sci.
MacKinnon, D.J.	B.Sc., M.A., Ph.D. (Ottawa)	Res. Sci.
McCready, R.G.L.	B.Sc., M.Sc. (Alberta); Ph.D. (Calgary)	Res. Sci.
McNamara, V.M.	B.Sc., B.Eng., M.A.Sc. (Toronto); P.Eng.	Res. Sci.
Mikhail, S.A.	B.Sc., Ph.D. (Cairo); Dr.Eng. (Norway)	Res. Sci.
Molnar, R.	B.Eng. (McGill); Ph.D. (Univ. of London); D.I.C.	Res. Sci.
Morrison, R.H.	B.Sc., Ph.D. (UBC)	Res. Sci.
Paquette, L.A.		Admin. Support
Pilgrim, R.F.	B.Sc. (Queen's)	Res. Sci.
Pouskouleli, G.	B.Sc. (Aristotelian Univ., Greece); M.Sc. (Université de Montréal); Ph.D. (McGill Univ.)	Res. Sci.
Prud'homme, P.J.A.		Technologist
Rajan, S.		Technologist
Ritcey, G.M.	B.Sc. (Dalhousie)	Res. Sci.
Rolko, V.H.E.	B.Sc. (Manitoba)	Chemist
Roxburgh, N.B.		Technologist
Salley, J.	B.Sc., (Ottawa)	Chemical Engineer

NAME	DEGREES	OCCUPATIONAL CATEGORY
Sanmugasunderam, V.	B.Sc. (Univ. of Ceylon); M.Sc. (Univ. of Wales); Ph.D. (UBC)	Res. Sci.
Shimano, D.Y.	B.Sc. (Concordia)	Phys. Sci.
Sutarno, R.	B.E., M.E., Ph.D. (N.S.T.C.); P.Eng.	Res. Sci.
Tan, K.G.	M.Sc.Chem. (Univ. of Aachem, Germany); Ph.D. (Carleton)	Res. Sci.
Taylor, J.B.		Technologist
Turcotte, A.M.		Technologist
Wallingford, G.		Technologist
Weatherell, C.	B.Sc., (Waterloo)	Chemist
Webster, A.H.	B.A., M.A., Ph.D. (UBC)	Res. Sci.
Wong, E.W.		Technologist
Wilson, L.J.	B.Sc. (McMaster)	Phys. Sci.
MINERAL PROCESSING LABORATORY		
Campbell, F.R.	Eng. D. (St. Francis Xavier); B.Eng. (N.S.T.C.); Ph.D. (London); D.I.C. (Imperial College)	Manager
Acta, J.	M.Sc. (UBC)	Phys. Sci.
Ahmad, A.	B.Sc., M.Sc., Ph.D. (New Brunswick)	Res. Sci.
Andrews, P.R.A.	B.Sc. (London); M.Eng.Sc. (Melbourne)	Res. Sci.
Beaulne, J.M.		Technologist
Besso, K.M.	B.Sc. (Montreal)	Phys. Sci.
Bilodeau, A.	B.Sc. (Laval)	Engineer

NAME	DEGREES	OCCUPATIONAL CATEGORY
Bilodeau, M.	B.Sc. (Laval)	Phys. Sci.
Boisclair, M.		Technologist
Brearly, G.D.		Technologist
Cabri, L.J.	B.Sc., M.Sc., Ph.D. (McGill)	Res. Sci.
Cameron, W.H.	B.Sc. (Queen's)	Phys. Sci.
Campbell, R.B.		Technologist
Canaday, J.D.	M.BA (Univ of Arizona) B.Sc. (Univ of Oklahoma); M.Sc. (Univ. of Calgary) M.Sc., Ph.D. (Univ. of Guelph);	Res. Sci.
Carette, G.G.	B.Sc. (Laval)	Eng.
Carrière, P.		Technologist
Chen, T.T.	B.Sc., M.Sc., Ph.D. (Cornell)	Res. Sci.
Chevrier, R.		Technologist
Childe, C.H.	B.Sc. (McGill)	Technologist
Chow, M.		Admin. Support
Cienske, B.A.	B.A. (Poland)	Phys. Sci.
Cimon, D.	B.Sc; M.Sc. (Laval)	Phys. Sci.
Collings, R.K.	B.Eng. (N.S.T.C.); P.Eng.	Res. Sci.
Cristovici, M.	B. Mining and Metallurgical Eng. (Bucharest); P.Eng.	Res. Sci.
Douglas, E.	B.Sc (Chem. Eng.) (Argentina); Ph.D. (McGill)	Res. Sci.
Doyle, D.M.	B.Sc. Min. Eng. (Michigan Technical Univ.)	Phys. Sci.
Feasby, D.G.	B.Sc., M.Sc. (Queen's)	Phys. Sci.

NAME	DEGREES	OCCUPATIONAL CATEGORY
Gilmour, T.		Technologist
Hanson, A.J.		Technologist
Hughson, M.R.	B.A. (Western Ontario)	Phys. Sci.
Jambor, J.L.	B.A., M.Sc. Ph.D. (Carleton)	Res. Sci.
Joly, T.		Admin. Support
Kelly, W.M.		Technologist
Kuriakose, A.K.	B.Sc., M.A., Ph.D. (Madras, India)	Res. Sci.
Lacelle, L.		Tech. Support
Laflamme, J.H.		Technologist
Laguitton, D.	Chem. Eng. (Rennes); D.Sc. (Laval)	Res. Sci.
Lamothe, J.M.	B. Mining Eng. (Ecole Polytechnique Montreal)	Res. Eng.
Lavallée, M.	B. Eng. Mining (McGill)	Phys. Sci.
Leblanc, D.		Tech. Support
Legault, C.		Admin. Support
Leigh, G.		Technologist
Lemieux, G.		Technologist
Leung, J.H.C.	B.Sc. (Taiwan); M.Sc. (Waterloo)	Phys. Sci.
Loucks, N.D.		Admin. Support
Mainwaring, P.R.	B.Sc. (UWO); Ph.D. (Toronto)	Res. Sci.
Malhotra, V.M.	B.Sc., B.E. (W. Australia)	Res. Sci.
Mathieu, G.I.	B.A., B.Sc. (Laval)	Res. Sci.

NAME	DEGREES	OCCUPATIONAL CATEGORY
McDonald, A.G.		Technologist
Mirkovich, V.V.	Ph.D. (Toronto)	Res. Sci.
Moon, K.S.	B. Sc., M.Eng. (Seoul National Univ.); M.A.Sc.; M. Eng. (UBC); Ph.D. (California);	Res. Sci.
Morin, L.		Technologist
Owens, D.R.		Technologist
Painter, K.E.	B.Sc. (Carleton)	Technologist
Petruk, W.	B.Eng., M.Sc., Ph.D. (McGill)	Res. Sci.
Pinard, R.G.		Technologist
Prud'homme, P.J.H.		Technologist
Quon, D.H.H.	B.Sc. (National Sun Yat Sen U); M.Sc. (Ohio State); Ph.D. (Michigan)	Res. Sci.
Racevic, M.		Technologist
Reynolds, V.G.	B.Sc. (Carleton)	Phys. Sci.
Rouleau, J.P.		Tech. Support
Sivasunderam, V.	B.Sc., (Srilanka) M.Sc. (Massachuetts)	Phys. Sci.
Soles, J.A.	B.A.Sc., M.A.Sc. (British Columbia), Ph.D. (McGill); P.Eng.	Res. Sci.
Stefanski, M.	B.Sc., M.Sc., Ph.D. (Katowce); Ph.D. (Krakow)	Phys. Sci.
Stemerowicz, A.I.	B.Sc. (Queen's); P.Eng.	Res. Sci.
Szymanski, J.T.	B.Sc., Ph.D. (London)	Res. Sci.
Venturino, M.		Admin. Support

NAME	DEGREES	OCCUPATIONAL CATEGORY
Wang, S.S.B.	B.Sc. (Hong Kong Baptist); M.Sc. (California); Ph.D. (Toronto)	Phys. Sci.
Wheat, T.A.	Ph.D. (Leeds)	Res. Sci.
Wilson, H.S.	B.E. (Saskatchewan)	Res. Sci.
Wilson, J.M.D.	B.Sc., M.A.Sc. (Queen's)	Phys. Sci.
NATIONAL URANIUM TAILINGS PROGRAM		
John, R.D.	B.Sc., (Loughborough); CIMA (London/Lambton)	Manager
Holmes, R.	B.Sc., M.Sc. (Windsor)	Project Manager
Ackerman, B.		Admin. Support
Renaud, F.		Admin. Support